January 30, 2014

Aircraft Performance Group Study Addendum

I. ACCIDENT

Description:	Impact with Sea Wall during Final Approach to Runway 28L
Location:	San Francisco International Airport (KSFO), San Francisco, CA
Date:	July 6, 2013
Time:	1128 Pacific Daylight Time (PDT)
Aircraft:	Boeing 777-200ER, HL7742
Operator:	Asiana Airlines
NTSB Number:	DCA13MA120

II. AIRCRAFT PERFORMANCE GROUP

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1.0 INTRODUCTION

On July 6, 2013 at 11:28 am Pacific daylight time, a Boeing 777-200ER, registration HL7742, operated by Asiana Airlines as flight 214, struck the sea wall short of runway 28L at San Francisco International Airport. The airplane was destroyed by impact forces and fire. Three of the 291 passengers were fatally injured. The flight was a regularly scheduled passenger flight from Incheon International Airport (RKSI), Seoul, Korea, and was operated under the provisions of 14 *Code of Federal Regulations* Part 129. Visual meteorological conditions prevailed at the time of the accident.

The NTSB Aircraft Performance Group Chairman traveled to Everett, WA on January 15, 2014 and worked with Boeing Aerodynamics Engineers on January 16–17th and 20th to evaluate and refine the B777-200ER event simulation match, the simulation match for a prior normal landing recorded on the Flight Data Recorder (FDR), and four hypothetical go-around scenarios based on Asiana flight 214 factual evidence. The nominal B777-200ER simulation provided a good match for the event airplane for the previous normal landing and an adequate match for the accident final approach flight path segment in free air. However, the nominal B777-200ER engineering simulation appears to yield conservative results (produced progressively less lift and higher sink rates than the accident airplane with increasing angle of attack and decreasing airspeed) during the low speed, high angle of attack accident flight path segment in ground effect. As a result, each of the four hypothetical go-around scenarios was evaluated first within the validated simulation envelope for free-air and ground effect and once again with the knowledge that the calculated go-around performance capability would be conservative in the ground effect region.

The simulation results indicated that the B777-200ER with Pratt & Whitney 4090 engines had adequate performance capability to accomplish a go-around initiated no later than 11 to 12 seconds prior to ground impact (depending on technique), assuming a minimum aft fuselage clearance during the maneuver of 30 feet above ground level (AGL). For reference purposes, the accident flight crew initiated a go-around by advancing the throttles about 7 seconds prior to ground impact.

2.0 TECHNICAL METHODS

The data sources and technical methods used in this study are described in this section.

2.1 CVR/FDR Event Overlay Plots

Cockpit Voice Recorder (CVR) transcript events and the Flight Data Recorder (FDR) angle of attack and radio altitude parameters were added to Figure 12 from the Aircraft Performance Group Study to correlate flight crewmember statements during short final approach with the previously calculated Precision Approach Path Indicator (PAPI) guidance, calculated pilot eye height, and calculated distance and time to impact. The composite plot data in Attachment 1, Figure A1.1 can be used to evaluate where the airplane was located on the flight path when CVR events such as “on glide path sir,” “it’s low,” “[sound of quadruple chime],” “speed,” “[sound similar to stick shaker…],” and “oh # go around” were recorded.

The FDR angle of attack and radio altitude parameters help identify the Asiana flight 214 operating point relative to the validated Boeing 777-200 engineering simulation envelope. For example, aerodynamic ground effect model terms are applicable when the airplane altitude is less than about one wing span (about 200 feet for the B777-200ER) above ground level.

2.2 Boeing 777-200ER Engineering Simulation Model

The Boeing engineering workstation simulation and pilot-in-the-loop simulator work for the Asiana flight 214 investigation was performed using the Boeing 777-200 Parallel SIMulation (PSIM) engineering tool,[1] Integrated Airplane Configuration (IAC) release B34_0_8 with Pratt and Whitney 4090 engines.

[1] The Boeing PSIM engineering tool supports both workstation simulation and pilot in-the-loop simulator needs for Boeing Commercial Airplane products. The PSIM integrated airplane simulation models consist of a six degree-of-freedom, nonlinear simulation with mathematical models for the airplane aerodynamics, propulsion, flight controls, autoflight systems, landing gear, hydraulic systems, mass properties, and the environment. The simulation models are updated and validated with flight test data and used to develop flight crew training simulator data packages.

2.2.1 Boeing 777-200 Simulation Model Validation

During commercial airplane development and certification programs, The Boeing Company routinely collects airplane flight test data to build and validate engineering models that are used to support stability and control, handling qualities, performance, loads, systems, auto-flight, flight crew training, and incident/accident investigation applications. Flight crew training simulator data packages are typically based on airplane engineering models validated by airplane flight test data, wind tunnel test data, and various analytical methods.

A key milestone in engineering simulator model validation is the development of the Proof-of-Match (POM) document, which compares calculated simulation results to available flight test data for specific flight test maneuvers at defined test conditions. For each maneuver type and condition selected to support the B777-200 POM document, calculated PSIM simulation results were quantitatively compared to corresponding flight test parameters using time history plots. In addition, tabulated data were used to record the initial conditions, trim setup, and math pilot setup for each test condition. For certain parameters, the difference between the calculated simulation results and the flight test data at each time (or trim snapshot) must not exceed a specified numeric tolerance.

The calculated simulation results presented in the B777-200 POM document were based on PSIM IAC 21, which was released on 10 Oct 2002. In response to an NTSB request, Boeing Aerodynamics Engineers reconstructed the following POM maneuvers relevant to the investigation of Asiana flight 214 using the current PSIM airplane simulation model build (IAC B34_0_8):

a. Engine Power Change Dynamics, Maneuver 7.1
b. Flap Change Dynamics (deployment and retraction), Maneuver 7.2
c. Gear Change Dynamics (deployment and retraction), Maneuver 7.4
d. Approach to Stall and Full Stall (free-air), Maneuver 7.9
e. Short Period, Maneuver 7.11
f. Normal Landing, Maneuver 9.1
g. All Engine Go-Around, Maneuver 9.6
h. Ground Effect Fly-bys, Maneuver 9.9

The NTSB compared the POM results from PSIM IAC 21 and IAC 34 and accepted the IAC 34 simulation results as the basis for Asiana flight 214 workstation simulation and pilot-in-the-loop simulator work. With the exception of Maneuver 7.9 (approach to stall and full stall) and very low speed, high angle of attack flight in ground effect, the flight test maneuvers listed above reflect airplane operation within the normal operating envelope.

The International Civil Aviation Organization (ICAO) Manual of Criteria for the Qualification of Flight Simulators, Second Edition, Document 9625 AN/938, dated 2003 was used to specify the required POM tolerances applicable to the B777-200 flight crew training simulator data package, which meets the level D (highest fidelity[2]) simulator qualification standard. The ICAO required parameter tolerances for the test maneuvers[3] listed above are documented in Table 1. Additional parameters commonly considered for simulation model development and

[2] Fidelity refers to the degree of similarity or realism between the integrated airplane simulation models and the actual airplane or the airplane pilot-in-the-loop simulator (with or without motion capability) and the actual airplane.
[3] B777-200 flight test data were used to quantify the fidelity of the B777-200 integrated airplane simulation for these test maneuvers and many additional test maneuvers and flight conditions required for the qualification of airplane flight simulators.

Table 1: ICAO Parameter Tolerance Requirements for Boeing 777-200 Simulator Proof-of-Match Maneuvers Reviewed by the NTSB

	ICAO Manual of Criteria for the Qualification of Flight Simulators, Second Edition Test Maneuver and Associated Parameter Tolerance Requirements							
Parameter (for Simulation Model Development and/or Validation Work)	**Power Change Dynamics, 7.1**	**Flap Change Dynamics, 7.2**	**Gear Change Dynamics, 7.4**	**Stalls, 7.9**	**Short Period, 7.11**	**Normal Landing, 9.1**	**All-Engine Go-Around, 9.6**	**Ground Effect Fly-bys, 9.9**
Angle of Attack, deg.	---	---	---	---	---	±1.5	±1.5	±1.0
Sideslip Angle, deg.	---	---	---	---	---	---	---	---
Flight Path Angle, deg.	---	---	---	---	---	---	---	---
Pitch Attitude, deg.	±1.5 or ±20% Pitch	±1.5 or ±20% Pitch	±1.5 or ±20% Pitch	---	±1.5	±1.5	±1.5	±1.0
Bank Angle, deg.	---	---	---	---	---	---	---	---
Heading, deg.	---	---	---	---	---	---	---	---
Body-Axis Roll Rate, deg./sec.	---	---	---	---	---	---	---	---
Body-Axis Pitch Rate, deg./sec.	---	---	---	---	±2.0	---	---	---
Body-Axis Yaw Rate, deg./sec.	---	---	---	---	---	---	---	---
Normal Load Factor, g	---	---	---	---	±0.1	---	---	---
Sink Rate, feet/min.	---	---	---	---	---	---	---	---
Altitude, feet	±100	±100	±100	---	---	±10 or ±10% of height	---	±5 or ±10% of height
Airspeed, knots	±3	±3	±3	±3[4]	---	±3	±3	±3
Ground speed, knots	---	---	---	---	---	---	---	---
Elevator, deg.	---	---	---	---	---	---	---	±1.0
Stabilizer, deg.	---	---	---	---	---	---	---	±0.5
Left Aileron, deg.	---	---	---	---	---	---	---	---
Right Aileron, deg.	---	---	---	---	---	---	---	---
Control Wheel, deg.	---	---	---	---	---	---	---	---
Rudder, deg.	---	---	---	---	---	---	---	---
Left Engine Net Thrust, pounds	---	---	---	---	---	---	---	±5.0%
Right Engine Net Thrust, pounds	---	---	---	---	---	---	---	±5.0%
C.G. Height, feet	---	---	---	---	---	---	---	---
Lateral Deviation, feet	---	---	---	---	---	---	---	---
Column Force, pounds (prior to g-break only)	---	---	---	±5.0 or ±10%[5],[6]	---	±5.0 or ±10%[5]	---	---

[4] For initial buffet, stall warning, and stall speeds.
[5] For aeroplanes with reversible flight control systems. The B777 does not have a reversible flight control system.
[6] Applies prior to g-break only.

POM validation work are included for reference. Boeing Engineering attempts to develop rational airplane simulation models that minimize the calculated differences between the corrected flight test data and calculated simulation parameters for each maneuver.

During simulation model development or update cycles, Boeing Engineering verifies that the required POM tolerances listed in Table 1 are satisfied and checks the quality of additional parameters to assess the overall quality of the match. If a parameter not listed in Table 1 differs significantly from flight test data, the difference is investigated and a model update is implemented, if possible, to improve the match.

2.2.2 Boeing 777-200 Simulation Model Limitations

In general, airplane simulation limitations are defined by an angle of attack and sideslip angle envelope based on data gathered from flight tests, wind tunnel tests, analytical methods, and extrapolation. Engineering confidence in the simulation envelope varies by data source from high (for flight validated data for a variety of test and flight conditions) to medium (for wind tunnel or analytical methods) to low (for extrapolated data). The approximate 777-200 simulation envelopes for flaps up and flaps down flight in free air were quantified and published in the Airplane Upset Recovery Training Aid, Revision 2, dated November 2008. Relevant excerpts of this document are provided in Attachment 2 for convenient reference. The description of the free-air simulation envelope data included in Attachment 2 notes that:

> "The flaps up data represent the maximums achieved at low speeds flaps up and do not imply that these values have been achieved at or near cruise speeds. For flaps down, the maximums were generally achieved at landing flaps, but are considered valid for the flaps down speed envelope."

Boeing 777-200 flight test data for maneuvers in ground effect were gathered for raw (uncorrected) angles of attack ranging from about -2° to +10° for altitudes between about 200 feet and 10 feet AGL. Raw flight test angle of attack data are available from about -2° to about +14° only for radio altitude values less than about 10 feet AGL.

Raw sideslip angle data range from about -6° to +7° for Boeing 777-200 flight test maneuvers in ground effect for altitudes between about 200 feet and about 40 feet AGL. The majority of the flight test sideslip angle data in ground effect are bounded by the values of ±2°. For radio altitude values less than about 40 feet AGL, available flight test sideslip angle data expand linearly from about -6° to -12° degrees and +7° to +12° degrees as radio altitude decreases from about 40 feet AGL to the ground.

The Boeing 777-200 aerodynamic ground effect simulation model was validated with flight test data for angle of attack values between -2° and +10° and sideslip angles between about ±2°. When the accident airplane exceeded 10° angle of attack in ground effect, it was operating outside the flight test validated envelope for the B777-200ER simulation model. Boeing Engineering and Flight Test Pilots consider very low speed, high angle of attack flight test maneuvers in ground effect to be hazardous beyond angle of attack values of +10° because of safety concerns.

2.3 Baseline Event Simulation Match

The baseline simulation match for the accident event was developed by Boeing Engineering between August 2013 and January 2014. The Boeing PSIM integrated airplane simulation model for the B777-200ER with P&W 4090 engines (at average engine thrust) was used in the workstation environment to match the event FDR data. The initial conditions for the baseline simulation setup were:

Pressure Altitude:	2560 feet
Radio Altitude:	2565 feet
Airspeed:	178 KCAS
Flaps:	5
Gear:	Down
Gross Weight:	423,680 pounds
Bank Angle:	0 degrees
Heading Angle:	296 degrees True
Ground Track Angle:	297.5 degrees
Temp (delta ISA):	3.15 °C
Altimeter:	29.92 in. Hg (actually 29.82 in. Hg for Asiana flight 214)

The simulation airplane was trimmed as follows: angle of attack was varied to target FDR normal acceleration; the center of gravity location was varied to target FDR-based body-axis pitch acceleration[7]; and flight path angle was varied to target FDR longitudinal acceleration. Engine thrust for each engine was calculated by using FDR engine N1 and Mach number data to lookup thrust in the P&W 4090 engine thrust deck.[8] The lateral-directional acceleration terms (body-axis roll, body-axis yaw, and side force) were calculated by the simulation at each time step based on the specified FDR aileron, flaperon, and rudder flight control surface inputs.

The leading edge slat, trailing edge flap,[9] elevator, stabilizer, aileron, flaperon, rudder, and individual spoiler surface positions were backdriven with interpolated FDR parameter data. This simulation backdrive strategy bypassed the flight controls, autoflight system, and flap load relief model logic. Calculated horizontal and vertical winds were derived from the available FDR parameters and used for in-air simulation calculations.

A pitch axis math pilot was used to calculate a small elevator bias to add to the nominal FDR elevator signal at each time step in order to track the FDR-based pitch attitude and calculated body-axis pitch rate. Similarly, a roll axis math pilot was used to calculate a small aileron and flaperon bias to add to the nominal FDR aileron and flaperon position at each time step in order to track the FDR-based roll attitude and calculated body-axis roll rate. The pitch and roll math pilot logic was implemented via a Proportional-Integral-Derivative (PID) closed-loop feedback control strategy. The math pilot attempts to minimize the error between the FDR-based parameter target(s) and the corresponding simulation value(s) at each time step.

[7] This trim strategy yielded a calculated center of gravity (c.g.) location of 24.5% mean aerodynamic chord (MAC) compared to an expected value of 28.5% MAC based on Asiana flight 214 airplane loading and estimated fuel burn. Boeing Engineering has been unable to resolve this c.g. discrepancy to date. An alternative approach would be to set the airplane c.g. to 28.5% MAC and trim with horizontal stabilizer. In this approach, the difference between the simulation trimmed stabilizer value and the FDR stabilizer value would define a constant bias to apply to the FDR horizontal stabilizer time history.

[8] Engine pressure ratio (EPR) was not an available independent variable in the P&W 4090 engine thrust deck used to calculate engine thrust for this study.

[9] Flaps 1 corresponds to leading edge slats extended to the sealed takeoff position with flaps up. For normal operations, the slat is designed to remain in the takeoff position for flaps 1 through 20 and extend to the fully extended (gapped) position when flaps 25 or 30 is selected, prior to the trailing edge flaps moving beyond the flaps 20 deflection. If the angle of attack exceeds a threshold value, the autoslat functionality for flaps 1 through 20 will extend the slat to the fully extended position to improve high angle of attack/stall characteristics.

Time history plots of the baseline simulation match are provided in Attachment 3, Figures A3.1 to A3.4. The first pair of figures document longitudinal and lateral-directional parameters as a function of time for a 100-second time period. The second pair of figures shows the same parameters zoomed in to a 40-second time period that ends at ground impact. The Asiana flight 214 FDR data, the calculated or corrected data derived from FDR data and parameter kinematic consistency checks, and the simulation data are depicted by the solid black, dashed blue, and dash-dot-dot line types, respectively, for each figure.

The longitudinal axis time history parameters are shown in Figures A3.1 and A3.3 in the following order, organized on the page from top to bottom, as a function of calculated time to impact (in seconds) on the horizontal axis: radio altitude, corrected computed airspeed, stick shaker, left engine throttle resolver angle, left engine calculated net thrust, calculated vertical speed, angle of attack, pitch attitude, elevator surface deflection, normal load factor, flap handle position, and landing gear lever position.

The corresponding lateral-directional axes time history parameters are similarly sequenced in Figures A3.2 and A3.4 as a function of calculated time to impact (in seconds) on the horizontal axis: radio altitude, corrected computed airspeed, stick shaker, left engine throttle resolver angle, left engine calculated net thrust, bank angle, left aileron surface deflection, heading, rudder surface deflection, lateral acceleration, flap handle position, and landing gear lever position.

The nominal B777-200ER simulation provides an adequate match for the accident final approach flight path segment in free air (see Figures A3.1 to A3.2). However, for unexplained reasons, the quality of the simulation vertical speed, angle of attack, pitch attitude, elevator deflection, and normal load factor match is degraded for a period of about 20 seconds beginning about 7 seconds after flaps 30 was selected.

In contrast to the free-air match, the nominal B777-200ER engineering simulation appears to yield conservative results (produces progressively less lift and higher sink rates than the accident airplane with increasing angle of attack and decreasing airspeed) during the low speed, high angle of attack accident flight path segment in ground effect (see Figures A3.3 to A3.4 for radio altitudes less than about 200 feet AGL). As a result, the simulation airplane flight path descends below the accident airplane path, computed airspeed increases, and the simulation airplane contacts the ground short of the accident airplane location.

The low energy state of the accident airplane yielded higher angle of attack values than Boeing Commercial Airplanes normally collects during the airplane flight test program to support development of the airplane simulation ground effect model. Boeing Engineering worked to determine if FDR or derived input data corrections, aerodynamic ground effect model improvements, or a combination of the two methods could improve the baseline event simulation match. Proposed plans to develop, incorporate, and justify high angle of attack refinements to the B777-200 simulation low speed aerodynamic ground effect model have been deferred due to resource constraints.

2.4 Previous Normal Landing Simulation Match

Prior landing data from the accident airplane FDR was requested by, provided to, and evaluated by Boeing Engineering to help understand the B777-200ER simulation model capability and limitations for the accident airplane operating in ground effect. Other B777 approach/landing and similar Boeing airplane model proprietary data were also analyzed.

In response to an NTSB request, Boeing Engineering demonstrated that the nominal PSIM 777-200ER airplane simulation model provided a reasonable match to a prior normal landing recorded on the accident airplane FDR. The landing at RKSI in Seoul, Korea was selected to demonstrate the previous landing simulation match. The initial conditions for the simulation setup were:

Pressure Altitude:	1,115 feet
Radio Altitude:	940 feet
Airspeed:	138 KCAS
Flaps:	30
Gear:	Down
Gross Weight:	397,440 pounds
Bank Angle:	-0.3 degrees
Heading:	323 degrees True
Ground track angle:	324.6 degrees
Temperature (delta ISA):	10.3 °C
Altimeter:	29.75 in. Hg

The airplane trim setup, backdriven parameter setup, and math pilot control strategy were similar to the baseline event simulation match setup outlined previously except for how engine thrust was determined. In the baseline accident event scenario, the simulation thrust was driven with values derived from FDR engine N1 and Mach number because calculating engine thrust from an idle engine TRA setting[10] resulted in too much engine thrust in the simulation model (i.e., calculated engine N1 at idle engine TRA was higher than the FDR engine N1). For the previous normal landing match, the simulation throttles were driven with FDR left and right engine TRA data. Since the throttles for this landing approach were not at idle, the FDR engine N1 could be more closely approximated in the simulation using FDR left and right engine TRA data to model thrust.

Time history plots of the previous normal landing simulation match are provided in Attachment 4, Figures A4.1 and A4.2 for the longitudinal and lateral-directional parameters, respectively. The parameter layout on these plots is similar to that described above for the baseline event simulation match plots, except that body axis pitch rate is shown on Figure A4.1 instead of normal load factor.

The nominal B777-200ER simulation yields a reasonable match to the event airplane FDR data for the previous normal landing during the 80-second period shown from about 950 feet radio altitude through main landing gear touchdown. The simulation radio altitude, engine N1, elevator deflection, bank angle, and heading parameter shape and magnitude characteristics are similar to the corresponding FDR parameters. The simulation airspeed and pitch attitude parameters remain within about 3 knots and 1.5° of the respective corrected FDR computed airspeed and FDR pitch attitude parameters, consistent with accepted POM tolerances for these parameters. The recorded FDR and the calculated simulation angle of attack values in ground effect both remain less than about +5°, well within the validated simulation envelope.

2.5 Alternate Scenario Simulation (Go-Around)

In August 2013, the Aircraft Performance Group defined four alternate control input (go-around) scenarios to evaluate using the B777-200ER engineering simulation in a workstation

[10] After the autopilot was disconnected and before the throttle levers were advanced following the quadruple chime aural alert, the accident approach was flown with left and right engine TRA at idle for a period of about 70 seconds.

environment. Each go-around scenario modeled a specific flight crew control input sequence accomplished in an attempt to correct the low airplane path and low airspeed condition by initiating a go-around. The four Asiana flight 214 go-around simulation scenarios considered in this study are defined in Table 2. The corrective action sequence of events for each scenario is based on 1) Asiana and/or Boeing flight crew training procedures and related guidance and/or 2) factual evidence recorded during Asiana flight 214.

Table 2: Corrective Action Go-Around Scenarios

Scenario #	Description	Elapsed Time (seconds)	Sequence of Events	Comments
1	Normal Go-Around	0.0 +0.5 +1.0 + ?? +0.5	TO/GA[11] – one push Pitch up at 2.5°/sec toward 15° pitch F20 selected Establish positive climb rate Gear lever up	Based on Boeing 777 Go-Around and Missed Approach guidance
2	Event Go-Around	0.0 +0.5	Advance throttles forward at event rate Pitch up at 4.0°/sec toward 15° pitch Do not select F20 Do not select gear up	Based on go-around technique attempted by Asiana flight 214
3	Hybrid 1 Go-Around	0.0 +0.5 +1.0 + ?? +0.5	Advance throttles forward at event rate Pitch up at 2.5°/sec toward 15° pitch F20 selected Establish positive climb rate Gear lever up	Scenario 1 with TO/GA – one push replaced by event throttle advance rate
4	Hybrid 2 Go-Around	0.0 +0.5 +1.0 + ?? +0.5	Advance throttles forward at event rate Pitch up at 4.0°/sec toward 15° pitch F20 selected Establish positive climb rate Gear lever up	Scenario 3 with pitch rate replaced by event pitch rate

A review of the existing guidance for Go-Around and Missed Approach in the Boeing 777 Flight Crew Operations Manual (FCOM) that was created for Asiana Airlines and the Boeing 777 Flight Crew Training Manual (FCTM) indicated that for an all-engine missed approach following a manual visual approach, a go-around is initiated by pushing the takeoff/go-around (TO/GA) switch on either engine throttle lever, calling for flaps 20, verifying or adjusting engine thrust as needed, rotating smoothly toward the go-around pitch attitude (15° is a

[11] For simulation purposes, one push of the TO/GA switch was equated to advancing the left and right engine throttle resolver angle (TRA) at a maximum rate of 10.5°/second from the idle position to the forward TRA limit. The FDR data indicated that the accident flight crew did not push the TO/GA switch to initiate the go-around, as evidenced by the facts that 1) the autopilot roll mode parameter did not transition to TO/GA, 2) the autopilot pitch mode parameter did not transition to TO/GA, 3) the left and right TRA parameter rate of advance exceeded the autothrottle servo rate for TO/GA – one push (autothrottle mode to THR) and 4) the autothrottle mode did not transition to THR REF as would be expected for TOGA – two pushes.

representative target), establishing positive climb rate, and then selecting landing gear up. If the airspeed is below the minimum maneuvering speed (top of the low speed amber band), the bank angle should not exceed 15°. If terrain contact is imminent, thrust levers should be advanced full forward.

The rationale for choosing go-around scenarios to simulate began with the intent to model the go-around initiation technique attempted by the flight crew of Asiana flight 214. The normal all-engine go-around initiation technique documented in existing Boeing 777 Go-Around and Missed Approach guidance was added next. The subsequent comparison of available FDR data to the normal go-around guidance identified differences in engine throttle lever advancement rate and target pitch attitude rate. The effect of these variables was evaluated by constructing two additional hybrid go-around scenarios. Initial conditions were based on the available airplane state factual evidence, starting along the baseline accident event simulation match at a pressure altitude of 2,560 feet, radio altitude of 2,565 feet, airspeed of 178 KCAS, flaps 5, and landing gear deployed.

Time 0.0 in Table 2 for each scenario corresponds to the first action accomplished to initiate the go-around. Subsequent sequential actions are accounted for with an incremental elapsed time allowance or a to-be-calculated incremental time allowance (for example, time required to establish positive climb rate). After time 0.0 in all scenarios, the simulation target pitch attitude was 15° and the angle of attack was reduced only as required to respect stick shaker warning (the simulation pitch axis math pilot targeted intermittent stick shaker[12]). To remain in the flight test validated simulation envelope, the calculated angle of attack in ground effect (below about 200 feet AGL) could not exceed 10°. When the go-around was initiated, the simulation pitch math pilot transitioned from tracking the accident event FDR pitch attitude and body-axis pitch rate to tracking the specified go-around pitch attitude and pitch rate. The simulation roll math pilot continued to target the accident event FDR roll angle and body-axis roll rate throughout the go-around maneuver.

The corrective action timing for each go-around scenario initially targeted the airplane configuration and state at the time of the quadruple chime aural alert. This target go-around timing was allowed to retreat via iteration using 0.5- to 1-second time decrements (positioning the airplane back up the path, away from the runway 28L threshold) as necessary, such that the calculated go-around solution respected the simulation angle of attack constraints in ground effect throughout the scenario time history. In addition, each calculated solution was constrained to provide a minimum aft fuselage ground clearance height of at least 30 feet AGL. The 30-foot clearance value was based on a runway threshold height of about 13 feet, an estimated 7-foot allowance for lead-in light mounting height above the pier catwalk, and a 10-foot allowance to account for the simulation calculated altitude tolerance.

A review of the accident airplane FDR angle of attack and radio altitude parameter history showed that the accident airplane was flying at angles of attack that exceeded the validated simulation ground effect model angle of attack envelope after the quadruple chime aural alert activated. In addition, the baseline event simulation match was unable to maintain the target altitude in ground effect even though the simulation angle of attack exceeded the FDR angle

[12] The purpose of targeting intermittent stick shaker is to extract the maximum lift capability out of the airplane for the given flight condition while avoiding wing stall, similar to the technique recommended for a windshear escape maneuver. The intended go-around simulation pitch attitude target parallels the windshear escape guidance found in the Asiana Airlines 777 FCOM, document D632W001-AAR, page MAN.1.11, dated June 13, 2011, which states "…the pitch attitude that results in intermittent stick shaker or initial buffet is the upper pitch attitude limit. Flight at intermittent stick shaker may be required to obtain positive terrain separation. Smooth, steady control will avoid a pitch attitude overshoot and stall." There is no evidence that Asiana flight 214 encountered a windshear event on short final approach.

of attack by several degrees. The simulation altitude deficit and artificially high angle of attack in ground effect suggested that use of the simulation ground effect model yielded a lift deficit at high angles of attack compared to the accident airplane. Recognition of this conservative simulation behavior resulted in a second set of go-around scenario calculations in which the requirement to respect the simulation angle of attack constraints in ground effect throughout the go-around scenario time history was dropped.

The available go-around simulation results and supporting figure locations are summarized in Table 3. Two groups of go-around simulation solutions exist; one family of solutions clustered 21 seconds prior to impact and the other family of solutions clustered 11 to 12 seconds prior to impact (depending on technique). The parameter layout on all the go-around figures is similar to that described previously for the baseline accident event simulation match plots.

Table 3: Summary of Corrective Action Go-Around Scenario Results

Scenario #	Description	Time Prior to Impact (seconds)	Appendix 5, Figures
1	Normal Go-Around	21	A5.1 – A5.2
2	Event Go-Around	21	A5.7 – A5.8
3	Hybrid 1 Go-Around	21	A5.13 – A5.14
4	Hybrid 2 Go-Around	21	A5.19 – A5.20
1	Normal Go-Around	12	A5.3 – A5.6
2	Event Go-Around	11	A5.9 – A5.12
3	Hybrid 1 Go-Around	12	A5.15 – A5.18
4	Hybrid 2 Go-Around	12	A5.21 – A5.24

Time history plots of the go-around simulation scenario results are provided in Attachment 5, Figures A5.1 to A5.6 for the normal go-around, Figures A5.7 to A5.12 for the event go-around technique, Figures A5.13 to A5.18 for the hybrid 1 go-around technique, and Figures A5.19 to A5.24 for the hybrid 2 go-around technique. The first two figures in each go-around technique plot set correspond to the longitudinal and lateral-directional axes parameters for a go-around solution initiated at about 200 feet AGL (to avoid exceeding the high angle of attack constraint for the flight test validated ground effect model).

The last four figures in each go-around technique plot set document the latest opportunity to accomplish a go-around using the prescribed technique (predicated on conservative simulation ground effect model results) and maintain an aft fuselage clearance of at least 30 feet AGL. The first pair (overview) and second pair (zoomed-in view) of figures in this set each illustrate the longitudinal and lateral-directional axes parameter time history results for the respective time period.

2.6 Stabilized Approach Criteria

Stabilized approach guidance from the Boeing 777 FCTM (dated June 2013), Airbus Flight Operations Briefing Notes (dated March 2004), and the Flight Safety Foundation (FSF) Approach-and-Landing Accident Reduction (ALAR) toolkit (dated 2009, later revised in 2010) is provided in Attachment 6. Current aviation industry guidance recommends the following elements for a stabilized approach in visual meteorological conditions (VMC):

Flight must be stabilized by 500 feet above airport elevation in VMC. *An approach is stabilized when all of the following criteria are met:*

1. The aircraft is on the correct flight path;
2. Only small changes in heading and pitch are required to maintain the correct flight path;
3. The aircraft speed is not more than V_{APP} +10 knots indicated airspeed and not less than V_{APP} - 5 knots;
4. The aircraft is in the correct landing configuration;
5. The sink rate is no greater than 1,000 fpm; if an approach requires a sink rate greater than 1,000 fpm, a special briefing should be conducted;
6. The power setting is appropriate for the aircraft configuration and is not below the minimum power for approach as defined by the aircraft operating manual;
7. All briefings and checklists have been conducted;
8. This item is not applicable to Asiana flight 214: guidance for instrument landing system (ILS) approaches and circling approaches;
9. Unique approach procedures or abnormal conditions requiring a deviation from the above elements of a stabilized approach require a special briefing.

An approach that becomes unstabilized below 500 feet above airport elevation in VMC requires an immediate go-around.

Based on the current industry stabilized approach guidance and available factual evidence, Asiana flight 214 had an excessive sink rate (greater than 1,000 fpm) and did not meet the appropriate power setting guidance for flaps 30, gear down at 500 feet above airport elevation. Moreover, below 500 feet above airport elevation, the approach was evaluated to be unstabilized due to sink rates greater than 1,000 fpm, airspeed less than V_{APP} - 5 knots, progressively larger changes in pitch required to maintain the flight path, and an incorrect vertical flight path evidenced by calculated PAPI guidance cues of 4 red lights.

2.7 Pilot-in-the-Loop Simulation Support

The Boeing, FAA, and NTSB members of the NTSB Aircraft Performance Group provided support for the NTSB Operations/Human Performance pilot-in-the-loop study conducted in the Boeing 777 Engineering Cab between January 21 and January 24, 2014. The FAA member was the designated FAA test pilot and pilot flying for the second pilot group that flew Condition 1 and 2 maneuvers. The Boeing and NTSB members provided simulation setup, validation, draft test plan development, data parameter recording, and data post-processing support.

3.0 RESULTS

The nominal B777-200ER simulation provided a good match for the event airplane for a prior normal landing and an adequate match for the accident final approach flight path segment in free air. However, the nominal B777-200ER engineering simulation appears to yield conservative results (produces progressively less lift and higher sink rates than the accident airplane with increasing angle of attack and decreasing airspeed) during the low speed, high angle of attack accident flight path segment in ground effect. As a result, each of the four hypothetical go-around scenarios was evaluated first within the validated simulation envelope for free-air and ground effect and once again with the knowledge that the calculated go-around performance capability would be conservative in the ground effect region.

The simulation results indicated that the B777-200ER with Pratt & Whitney 4090 engines had adequate performance capability to accomplish a go-around initiated no later than 11 to 12 seconds prior to ground impact (depending on technique), assuming a minimum aft fuselage clearance during the maneuver of 30 feet AGL. For reference purposes, the accident flight crew initiated a go-around by advancing the throttles about 7 seconds prior to ground impact.

A partial summary of short final approach events related to flight crewmember airspeed awareness, flight path awareness, and crew corrective action/timing is provided in Table 4 as a function of event, event source, and calculated time to impact. For convenient context reference, the two simulation results that best characterize the B777-200ER go-around performance capability have been added to Table 4 and highlighted in blue text.

4.0 ATTACHMENTS

Attachment 1: Cockpit Voice Recorder Event Overlay on Flight Data Recorder Data

Attachment 2: B777-200 Engineering Simulation Model Limitations (Free Air)

Attachment 3: Accident Airplane Baseline Event Simulation Match

Attachment 4: Simulation Match for Accident Airplane Previous Normal Landing

Attachment 5: Alternate Airplane Configuration Scenarios (Go-Around)

Attachment 6: Stabilized Approach Criteria

Table 4: Asiana Flight 214 Short Final Approach Events/Options (Speed, Path, Go-Around)

Event	Source	Time to Impact (seconds)	Comment
Airspeed drops and remains below MCP selected speed.	FDR	-35.2	---
HOT-1 on glide path sir.	CVR	-30.5	---
Airspeed drops and remains below $V_{REF\ 30}$.	FDR	-27.0	---
PAPI WRRR	PAPI & Pilot eye height calculations	-26.2	---
Go-Around Assured	B777-200ER Simulation	-21	Go-around at 200 feet AGL. Airplane remains within normal operating region of flight test validated PSIM models.
PAPI RRRR	PAPI & Pilot eye height calculations	-19.3	---
CAM two hundred. [electronic voice]	CVR	-18.0	---
CAM-1 <it's low.>	CVR	-16.7	---
Normal Go-Around Still Possible	B777-200ER Simulation	-12	Go-around at 110 feet AGL. Minimum aft fuselage clearance 30 feet AGL. The PSIM ground effect model is conservative at angles of attack above +10°.
Quadruple Chime Aural Alert	CVR	-11	---
CAM one hundred. [electronic voice]	CVR	-8.7	---
CAM-1 speed.	CVR	-7.5	---
Left and Right Engine Throttles Advanced	FDR	-7	---
Control Column Near Full Aft Position	FDR	-4.5	---
CAM fifty. [electronic voice]	CVR	-4.5	---
CAM [sound similar to stick shaker for ~2.24 sec]	CVR	-3.9	---
Control Column Near Neutral Position	FDR	-2.8	---
HOT-1 oh # go around.	CVR	-2.5	---
Control Column Maintains Full Aft Position	FDR	-2.0	---

Attachment 1: CVR Event Overlay on FDR Data

ASIANA AIRLINES BOEING 777-200ER FLIGHT 214 FINAL APPROACH; JULY 6, 2013

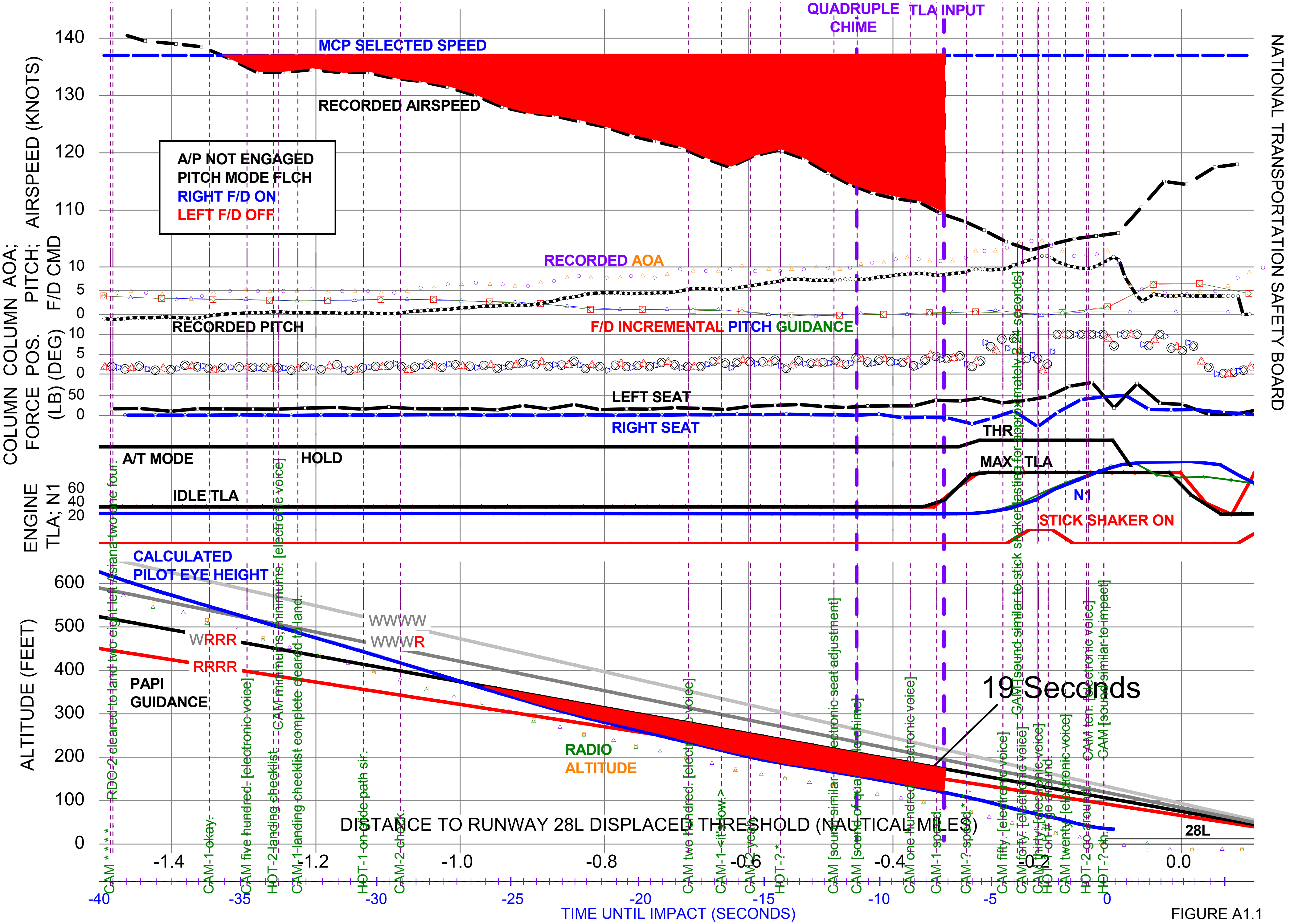


FIGURE A1.1

Attachment 2: B777-200 Simulation Model Limitations (Free Air)

November 2008

To: Nicholas A. Sabatini
Associate Administrator for Aviation Safety
AVS-1
800 Independence Avenue, SW
FOB 10-A, Room 1000 West
Washington, DC 20591

cc: Dan Jenkins
Manager, Air Carrier Training Branch
AFS-210
800 Independence Avenue, SW
FOB 10-A, Room 831
Washington, DC 20591

cc: Greg Kirkland
Acting Manager, Air Transportation Division
AFS-200
800 Independence Avenue, SW
FOB 10-A, Room 831
Washington, DC 20591

cc: Gloria LaRoche
Aviation Safety Inspector
Air Carrier Training, AFS-210
800 Independence Avenue, SW
FOB 10-A, Room 831
Washington, DC 20591

Dear Mr. Sabatini:

We are pleased to provide you this "Airplane Upset Recovery Training Aid Revision 2". This document was developed in response to FAA request for us to convene an industry and government working group to develop guidance to flight crews as it pertains to issues associated with operations, unintentional slowdowns, and recoveries in the high altitude environment. In the interest of defining an effective document, it has been decided to introduce this package as a supplement to the Airplane Upset Recovery Training Aid first released in 1998. While the Airplane Upset Recovery Training Aid specifically addressed airplanes with 100 seats or greater, the information in this supplement is directly applicable to most jet airplanes that routinely operate in this environment. This supplemental information has been inserted in the Airplane Upset Recovery Training Aid Rev 2 completed October 2008.

As a group of industry experts, we are confident we achieved the goal of defining a reference that will be effective to educate pilots so they have the knowledge and skill to adequately operate their airplanes and prevent upsets in a high altitude environment. The key point is that no reference material published is of value unless it is used. To that end, we implore the FAA to produce language to support implementation of this material that will motivate operators to use it. Indeed, the current Airplane Upset Recovery Training Aid serves as an excellent example of a collaborative reference produced at the insistence of the FAA, with little endorsement or requirement for implementation. The industry result is an assortment of products available with no standard reference. This competes against the very motivation for producing a collaborative document in the first place.

Several recommendations have been provided to our team from the FAA certification group. We are encouraged they continue to look at ways to improve future aircraft. We are confident this supplement and the Airplane Upset Recovery Training Aid, for airplanes in service today, are effective references, if implemented, to provide flight crews information and skills that respond to the suggestions this FAA group are studying.

Your review and agreement to the attached Training Aid will allow us to produce and deliver it to industry.

Sincerely,

Captain Dave Carbaugh
The Boeing Company
Co-chair Upset Recovery Industry Team

Captain Larry Rockliff
Airbus
Co-chair Upset Recovery Industry Team

Bob Vandel
Flight Safety Foundation
Co-chair Upset Recovery Industry Team

training guide can be utilized as recommended or can be configured into e-based training if desired. Figure 1 shows a suggested Academic Training Program.

3.1.4 Additional Academic Training Resources

The *Airplane Upset Recovery Training Aid* is provided in CD-ROM DOS format. The complete document and the two-part video are included in this format. This allows for more flexible training options and makes the information readily available to pilots. For example, the Pilot Guide (Sec. 2 of the document) may be printed from the CD-ROM format and distributed to all pilots.

3.2 Simulator Training Program

The Simulator Training Program addresses techniques that pilots should use to recover an airplane that has been upset. Training and practice are provided to allow the pilot to, as a minimum, recover from nose-high and nose-low airplane upsets. The exercises have been designed to meet the following criteria:

a. Extensive simulator engineering modification will not be necessary.

b. All exercises will keep the simulator within the mathematical models and data provided by the airplane manufacturer.

c. Exercises will not result in negative or counterproductive training.

To be most effective, simulator training requires the pilot-in-training to be familiar with the material in the Academic Training Program.

Simulator training exercises are developed so that an operator needs only minimum training capability to encourage the implementation of an effective airplane upset recovery training program. The training exercises may be initiated by several means:

a. Manual maneuvering to the demonstration parameters.

b. Automated simulator presets.

c. Stabilizer trim to induce the demonstration as best suits the pilot-in-training requirements.

d. Other appropriate airplane-system, flight-control, or engine malfunctions.

Instructors may be called on to maneuver the simulator to assist the pilot-in-training in order to obtain the desired parameters and learning objectives. The instructors need to be properly trained to avoid nonstandardized or ineffective training.

3.2.1 Simulator Limitations

Simulator capabilities have evolved to provide accurate duplication of airplane characteristics within the normal operating envelope. Since the normal working environment of the airline pilot does not encompass vertical or lateral load transients, simulator limitations in that area are negligible. However, airplane upsets often will involve g load excursions and these cannot be duplicated within the simulator environment. They have not been designed for the purpose of replicating upsets, and as such, whenever maneuvering involves vertical or lateral loading, the realism degrades. This is a very important point for both the trainee and the instructor. Instructional content must acknowledge this limitation and fortify instructional content based upon the trainee's prior flight experience with g load excursions. Without this instructional input, a positive learning goal can be transformed into a negative learning experience.

Simulator fidelity relies on mathematical models and data provided by the airplane manufacturer. The simulator is updated and validated by the manufacturer using flight data acquired during the flight test program. Before a simulator is approved for crew training, it must be evaluated and qualified by a regulatory authority. This process includes a quantitative comparison to actual flight data for certain test conditions, such as those specified in the International Civil Aviation Organization (ICAO) *Manual of Criteria for the Qualification of Flight Simulators*. These flight conditions represent airplane operation within the normal operating envelope.

When properly accomplished, the training recommended in this training aid should be within the normal operating envelope for most simulators. However, operators must assess their simulators to ensure their ability to support the exercises. This assessment should include, at a minimum, aerodynamic math models; their associated data tables; and the performance capabilities of visual, flight instrument, and motion systems to support maneuvers performed in the simulator.

Appendix 3-D, "Flight Simulator Information," was developed to aid operators and training organizations in assessing their simulators. The information is provided by airplane manufacturers and based on the availability of information. Simulator manufacturers are another source for information.

The simulation may be extended to represent regions outside the typical operating envelope by using reliable predictive methods. However, flight data are not typically available for conditions where flight testing would be very hazardous. From an aerodynamic standpoint, the regimes of flight that are not generally validated fully with flight test data are the stall region and the region of high angle of attack with high-sideslip angle. While numerous approaches to a stall or stalls are flown on each model (available test data are normally matched on the simulator), the flight controls are not fully exercised during an approach to stall, or during a full stall, because of safety concerns. Training maneuvers in this regime of flight must be carefully tailored to ensure that the combination of angle of attack and sideslip angle reached in the maneuver do not exceed the range of validated data or analytical/extrapolated data supported by the airplane manufacturer. The values of pitch, roll, and heading angles, however, do not affect the aerodynamics of the simulator or the validity of the training as long as angle of attack and sideslip angles do not exceed values supported by the airplane manufacturer. For example, a full 360-deg roll maneuver conducted without exceeding the valid range of the angle of attack and sideslip angle will be correctly replicated from an aerodynamic standpoint. However, the forces imposed on the pilot and the ratio of control forces to inertial and gravity forces will not be representative of the airplane.

Simulator technology continues to improve, which allows more training opportunities. However, trainers and pilots must understand that simulators still cannot replicate all things. For example, sustained g forces, both negative and positive, are not replicated. This means that a pilot cannot rely on complete sensory feedback that would be available in an actual airplane. Additionally, such things as loose items that would likely be floating in the cockpit during a negative-g situation are clearly not replicated in the simulator. However, a properly programmed simulator should provide accurate control force feedback (absent any sustained g loading), and the motion system should provide airframe buffet consistent with the aerodynamic characteristics of the airplane which could result from control input during certain recovery situations.

The importance of providing feedback to a pilot when control inputs would have exceeded airframe, physiological, or simulator model limits must be recognized and addressed. Some simulator operators have effectively used a simulator's "crash" mode to indicate limits have been exceeded. Others have chosen to turn the visual system red when given parameters have been exceeded. Simulator operators should work closely with training departments in selecting the most productive feedback method when selected parameters are exceeded.

3.2.2 Training Objectives

The objective of the Simulator Training Program is to provide pilots with the necessary experience and skills to

a. Recognize and confirm airplane upset.

b. Gain confidence and understanding in maneuvering the airplane during upsets.

c. Successfully apply proper airplane upset recovery techniques.

3.2.3 Simulator Training Syllabus

The training given during initial, transition, and recurrent phases of training should follow a building block approach. The first time an upset is introduced, it should be well briefed and the pilot should have general knowledge of how the airplane will react. Since full limits of control forces may be necessary during a recovery from an upset, it may be appropriate to allow the pilot opportunity for maneuvering using all flight control inputs.

Exercises are initiated by the instructor pilot. Once the desired upset situation is achieved, the pilot-in-training then applies appropriate techniques to return the airplane to its normal flight regime or to maneuver the airplane during certain demonstrations, depending on the exercise. It may take several iterations before the pilot-in-training has the required skills for recovering the airplane.

3.2.4 Pilot Simulator Briefing

Pilots should be familiar with the material in the Ground Training Program before beginning Airplane Upset Recovery Training. However, a briefing should be given to review the following:

Flight Simulator Information

General Information

The ability of the simulators in existence today to adequately replicate the maneuvers being proposed for airplane upset recovery training is an important consideration. Concerns raised about simulators during the creation of the *Airplane Upset Recovery Training Aid* include the adequacy of the hardware, the equations of motion, and the aerodynamic modeling to provide realistic cues to the flight crew during training at unusual attitudes.

It is possible that some simulators in existence today may have flight instruments, visual systems or other hardware that will not replicate the full six-degree-of-freedom movement of the airplane that may be required during unusual attitude training. It is important that the capabilities of each simulator be evaluated before attempting airplane upset training and that simulator hardware and software be confirmed as compatible with the training proposed.

Properly implemented equations of motion in modern simulators are generally valid through the full six-degree-of-freedom range of pitch, roll, and yaw angles. However, it is possible that some existing simulators may have equations of motion that have unacceptable singularities at 90, 180, 270, or 360 deg of roll or pitch angle. Each simulator to be used for airplane upset training must be confirmed to use equations of motion and math models (and associated data tables) that are valid for the full range of maneuvers required. This confirmation may require coordination with the airplane and simulator manufacturer.

Operators must also understand that simulators cannot fully replicate all flight characteristics. For example, motion systems cannot replicate sustained linear and rotational accelerations. This is true of pitch, roll, and yaw accelerations, and longitudinal and side accelerations, as well as normal load factor, "g's." This means that a pilot cannot rely on all sensory feedback that would be available in an actual airplane. However, a properly programmed simulator should provide accurate control force feedback and the motion system should provide airframe buffet consistent with the aerodynamic characteristics of the airplane which could result from control input during certain recovery situations.

The importance of providing feedback to a pilot when control inputs would have exceeded airframe, physiological, or simulator model limits must be recognized and addressed. Some simulator operators have effectively used a simulator's "crash" mode to indicate limits have been exceeded. Others have chosen to turn the visual system red when given parameters have been exceeded. Simulator operators should work closely with training departments in selecting the most productive feedback method when selected parameters are exceeded.

The simulation typically is updated and validated by the airplane manufacturer using flight data acquired during the flight test program. Before a simulator is approved for any crew training, it must be evaluated and qualified by a national regulatory authority. This process includes a quantitative comparison of simulation results to actual flight data for certain test conditions such as those specified in the ICAO *Manual of Criteria for the Qualification of Flight Simulators*. These flight conditions represent airplane operation within the normal operating envelope.

The simulation may be extended to represent regions outside the typical operating envelope using wind tunnel data or other predictive methods. However, flight data are not typically available for conditions where flight testing would be very hazardous. From an aerodynamic standpoint, the regimes of flight that are usually not fully validated with flight data are the stall region and the region of high angle of attack with high sideslip angle where there may be separated airflow over the wing or empennage surfaces. While numerous approaches to stall or stalls are flown on each model (available test data are normally matched on the simulator), the flight controls are not fully exercised during an approach to stall or during a full stall, because of safety concerns. Also, roll and yaw rates and sideslip angle are carefully controlled during stall maneuvers to be near zero; therefore, validation of derivatives involving these terms in the stall region is not possible. Training maneuvers in this regime of flight must be carefully tailored to ensure that the combination of angle of attack and sideslip angle reached during the maneuver does not exceed the range of validated data or analytical/extrapolated data supported by the airplane manufacturer.

Values of pitch, roll, and heading angles, however, do not directly affect the aerodynamic characteristics of the airplane or the validity of simulator training as long as angle of attack and sideslip angles do not exceed values supported by the airplane manufacturer. For example, the aerodynamic characteristics of the upset experienced during a 360-deg roll maneuver will be correctly replicated if the maneuver is conducted without exceeding the valid range of angle of attack and sideslip.

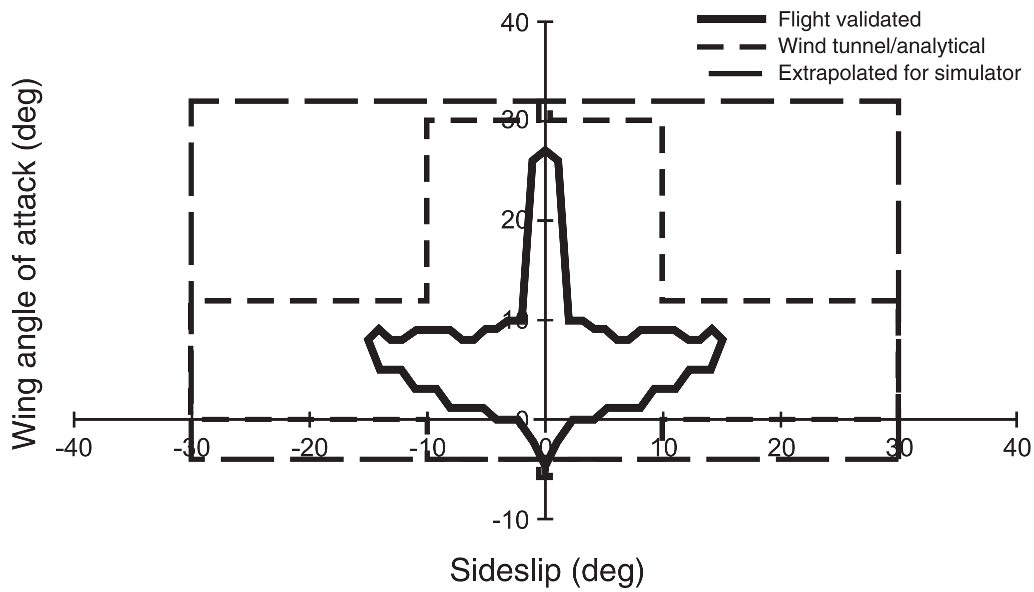
Simulator Alpha-Beta Data Plots

The aerodynamic model for each simulation may be divided into regions of various "confidence levels," depending on the degree of flight validation or source of predictive methods if supported by the airplane manufacturer, correctly implemented by the simulator manufacturer and accurately supported and maintained on an individual simulator. These confidence levels may be classified into three general areas:

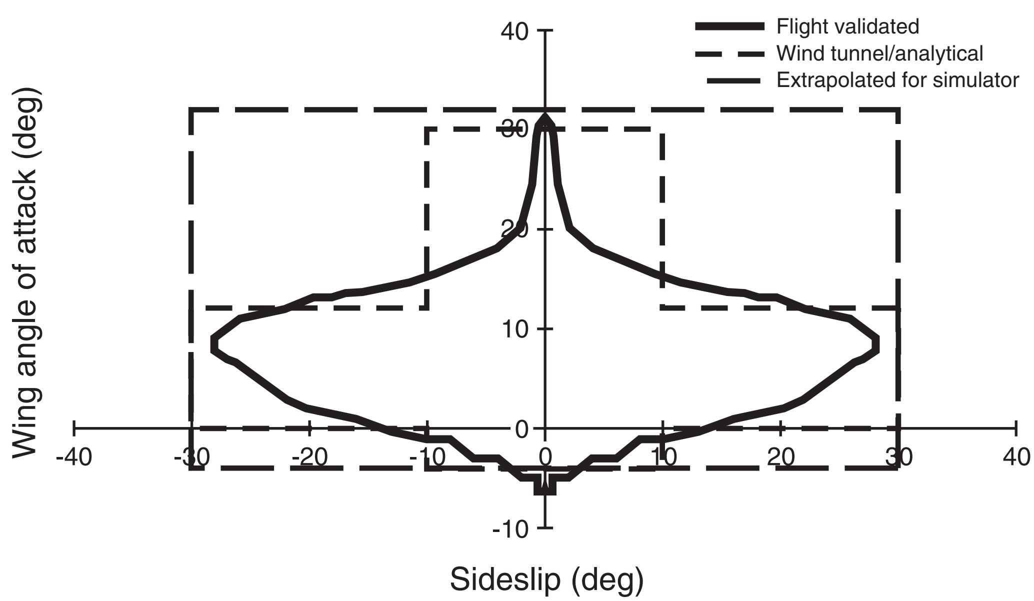
1. High: Validated by flight test data for a variety of tests and flight conditions.
2. Medium: Based on reliable predictive methods.
3. Low: Extrapolated.

The flaps up data represent the maximums achieved at low speeds flaps up and do not imply that these values have been achieved at or near cruise speeds. For flaps down, the maximums were generally achieved at landing flaps, but are considered valid for the flaps down speed envelope.

777 Flaps Up Alpha/Beta Envelope



777 Alpha/Beta Envelope **(Flaps Down)**



Attachment 3: Baseline Event Simulation Match

Figure A3.1: Baseline Event Simulation Match

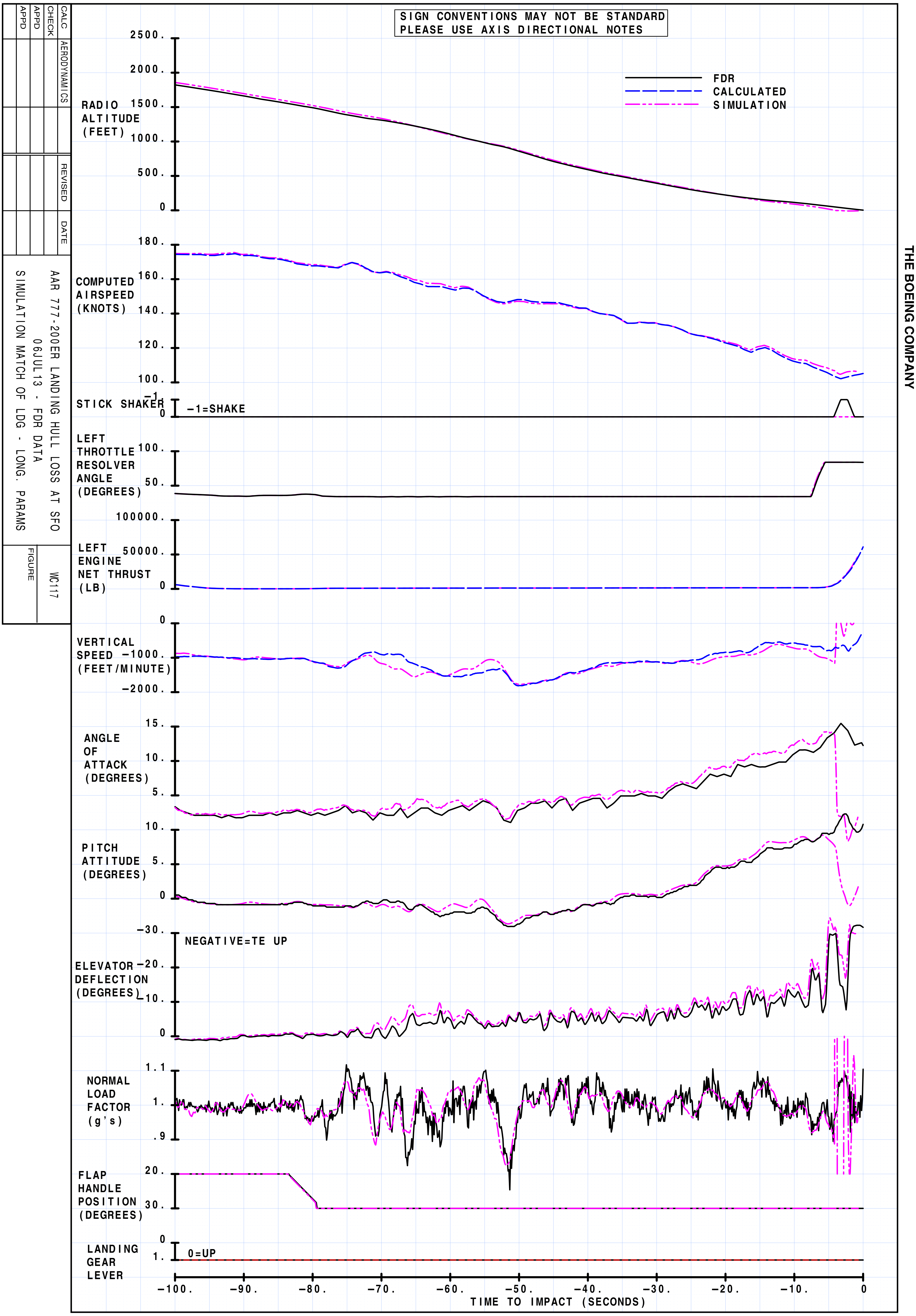


Figure A3.2: Baseline Event Simulation Match

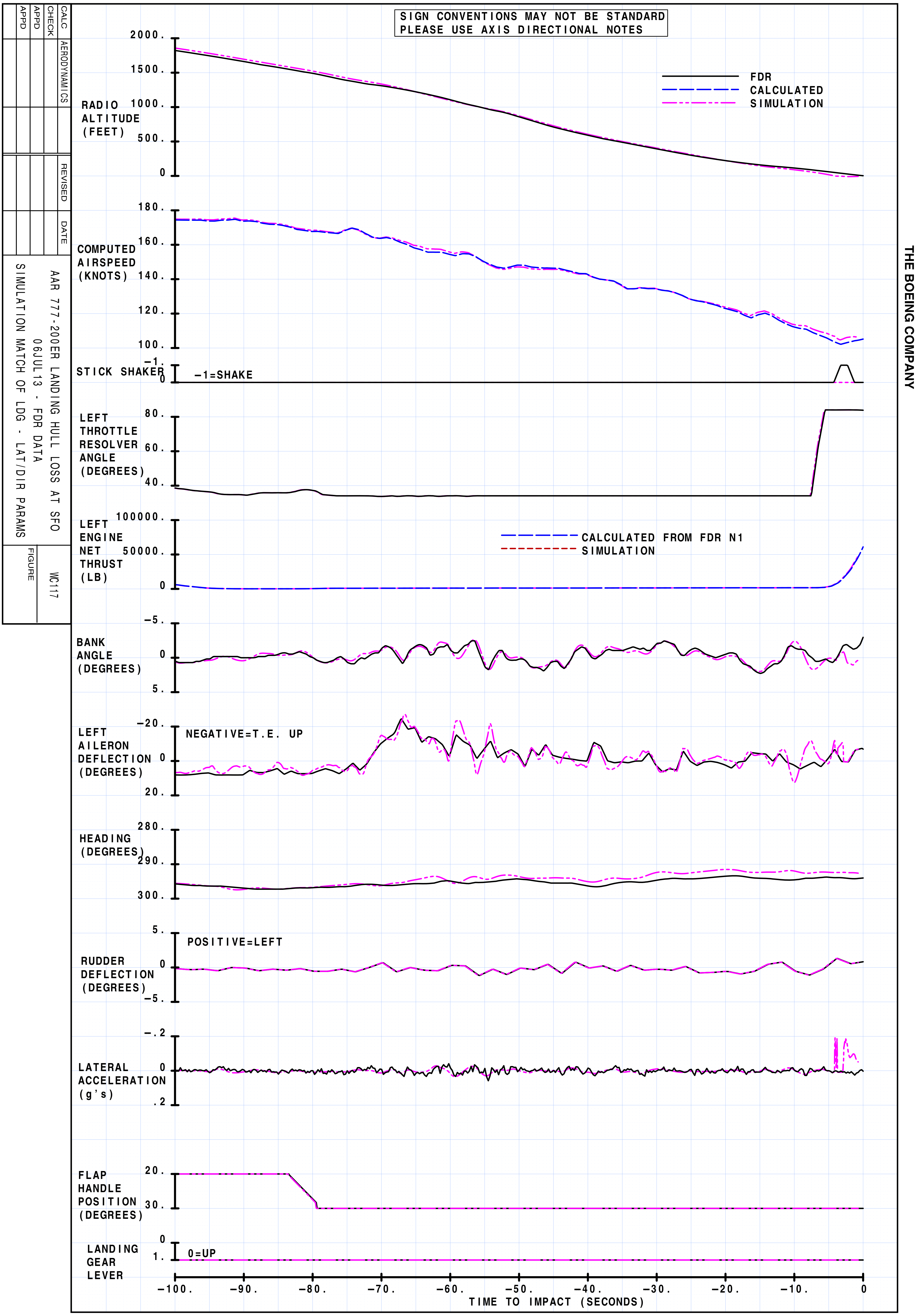


Figure A3.3: Baseline Event Simulation Match

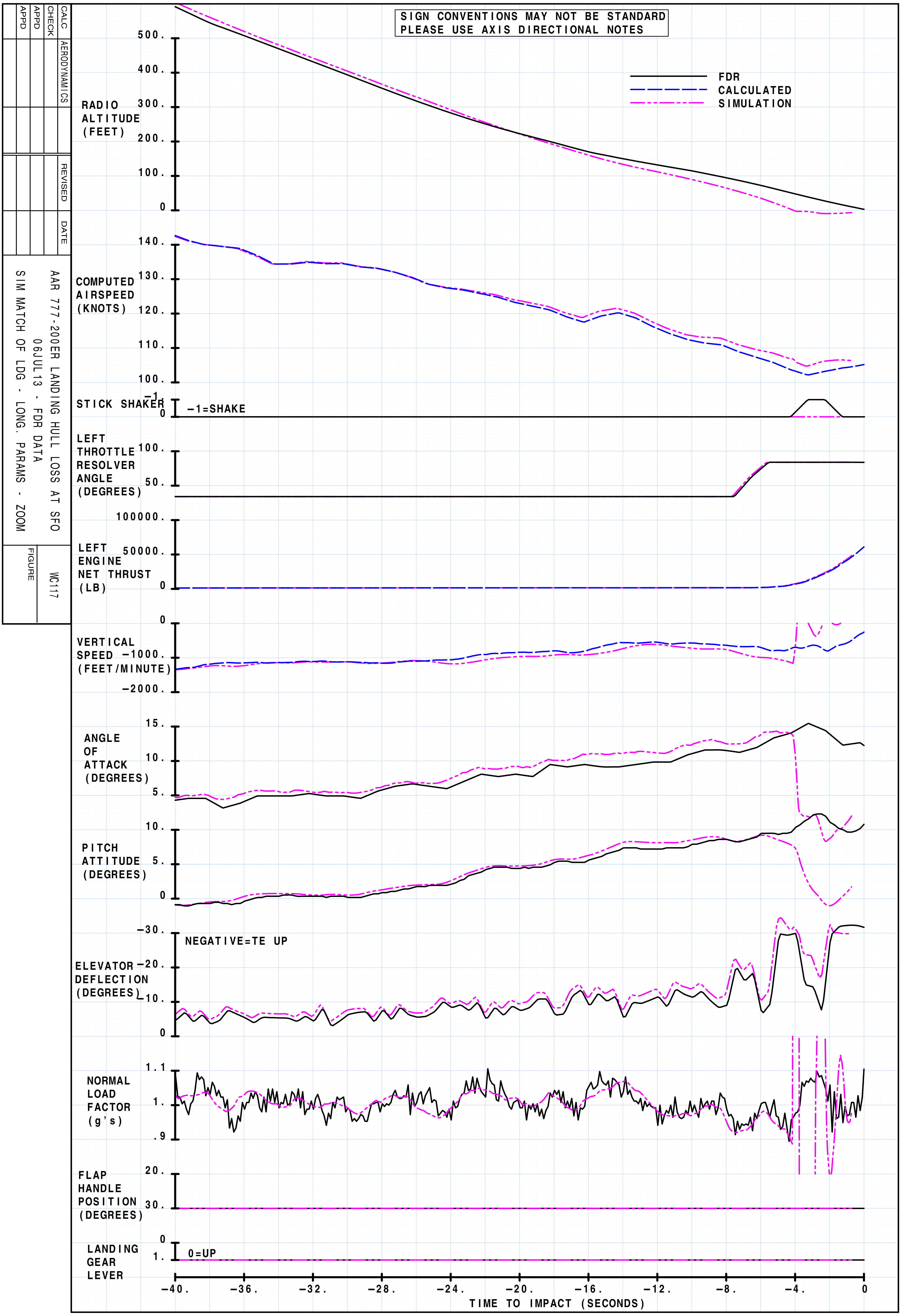
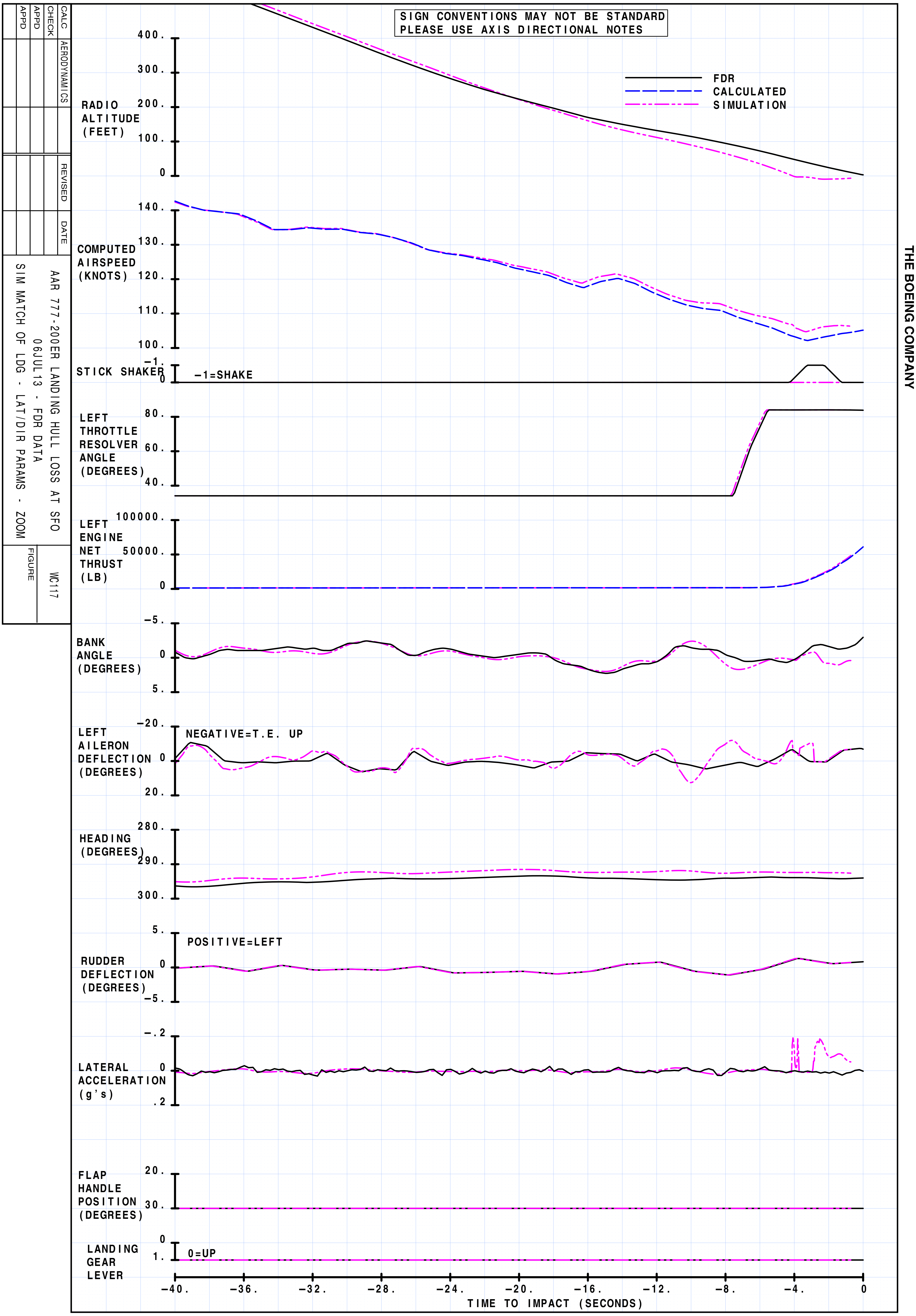


Figure A3.4: Baseline Event Simulation Match



Attachment 4: Previous Normal Landing Simulation Match

Figure A4.1: Previous Normal Landing Simulation Match

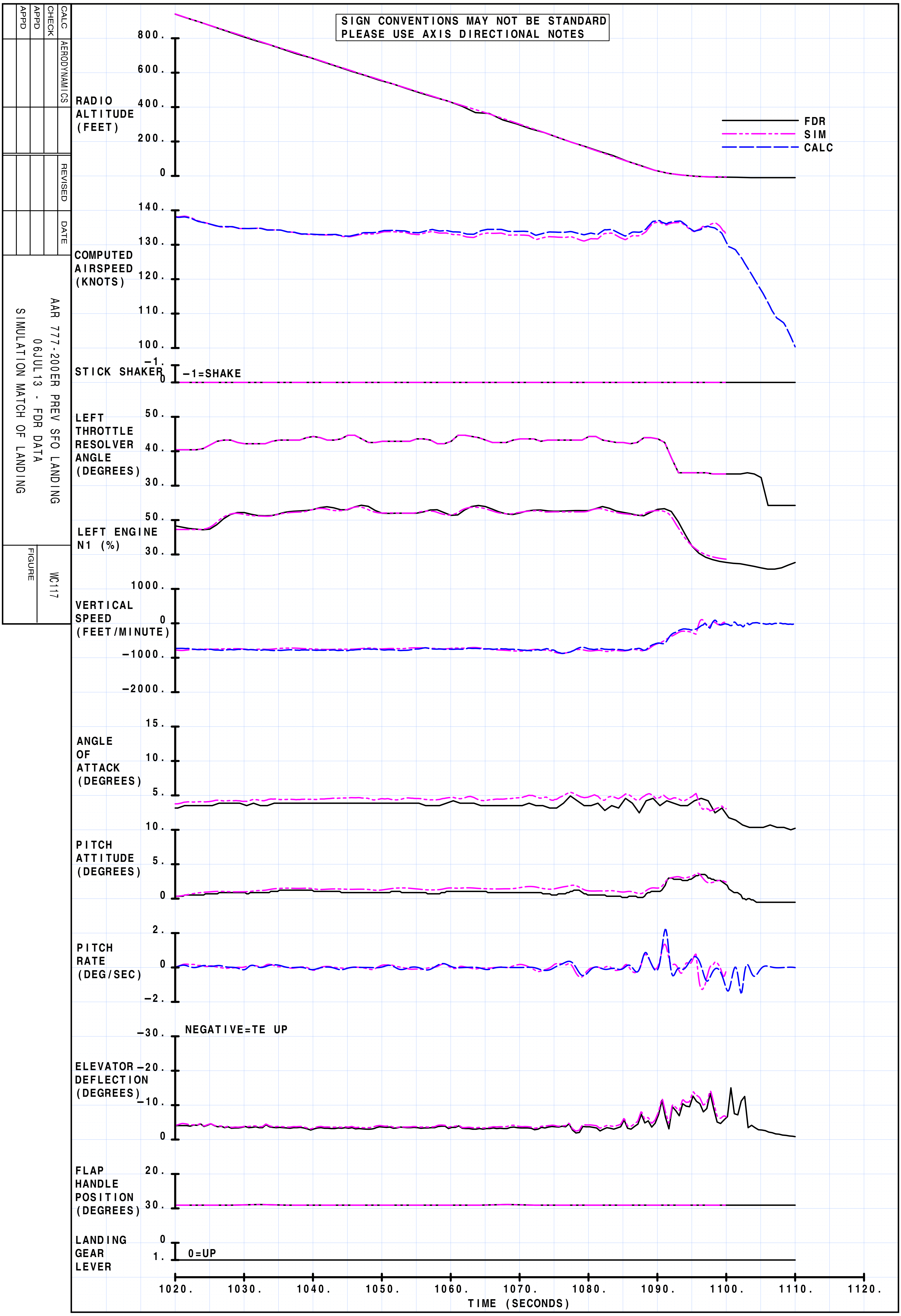
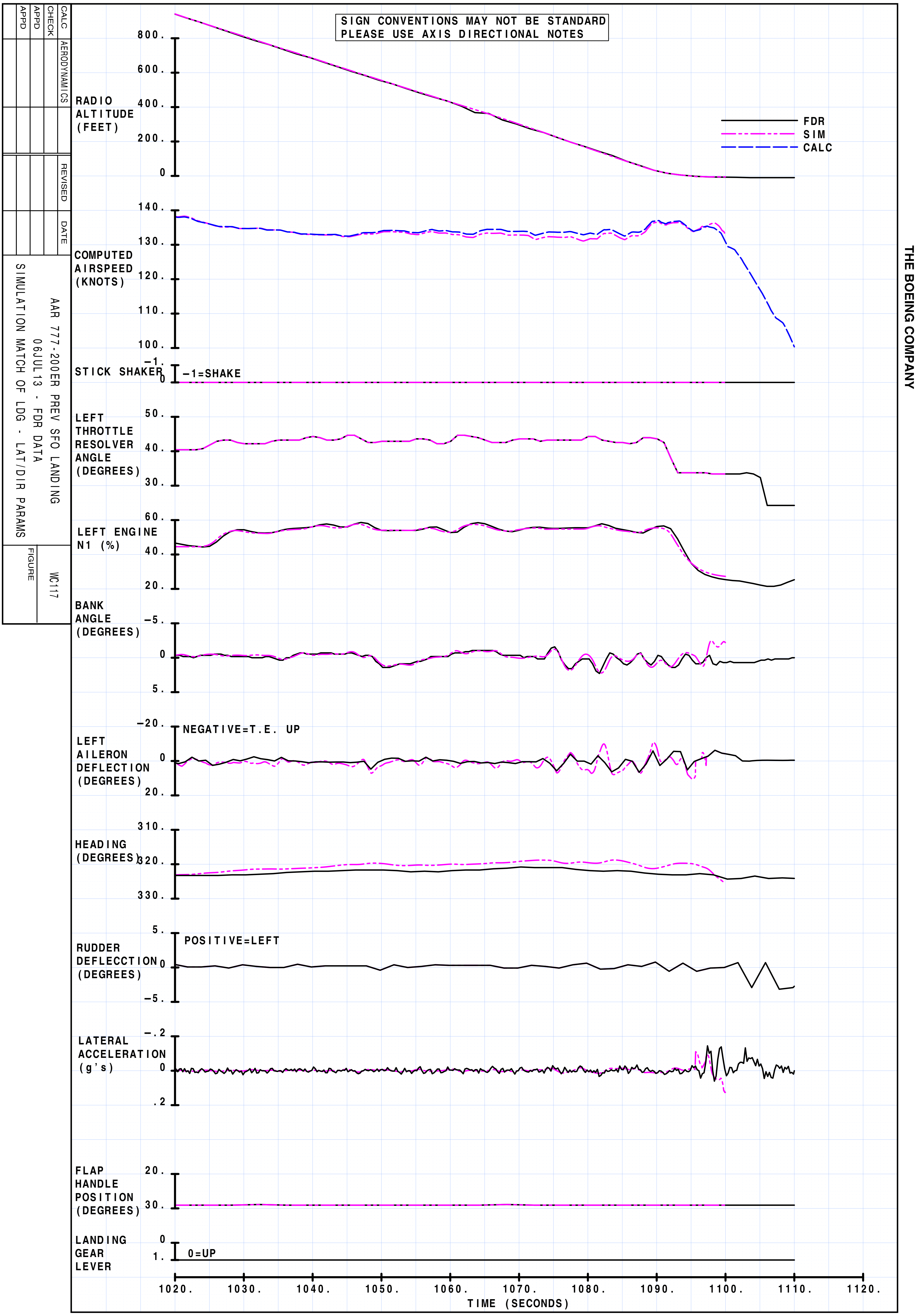


Figure A4.2: Previous Normal Landing Simulation Match



Attachment 5: Alternate Configuration Scenarios (Go-Around)

Figure A5.1: Normal Go-Around Simulation

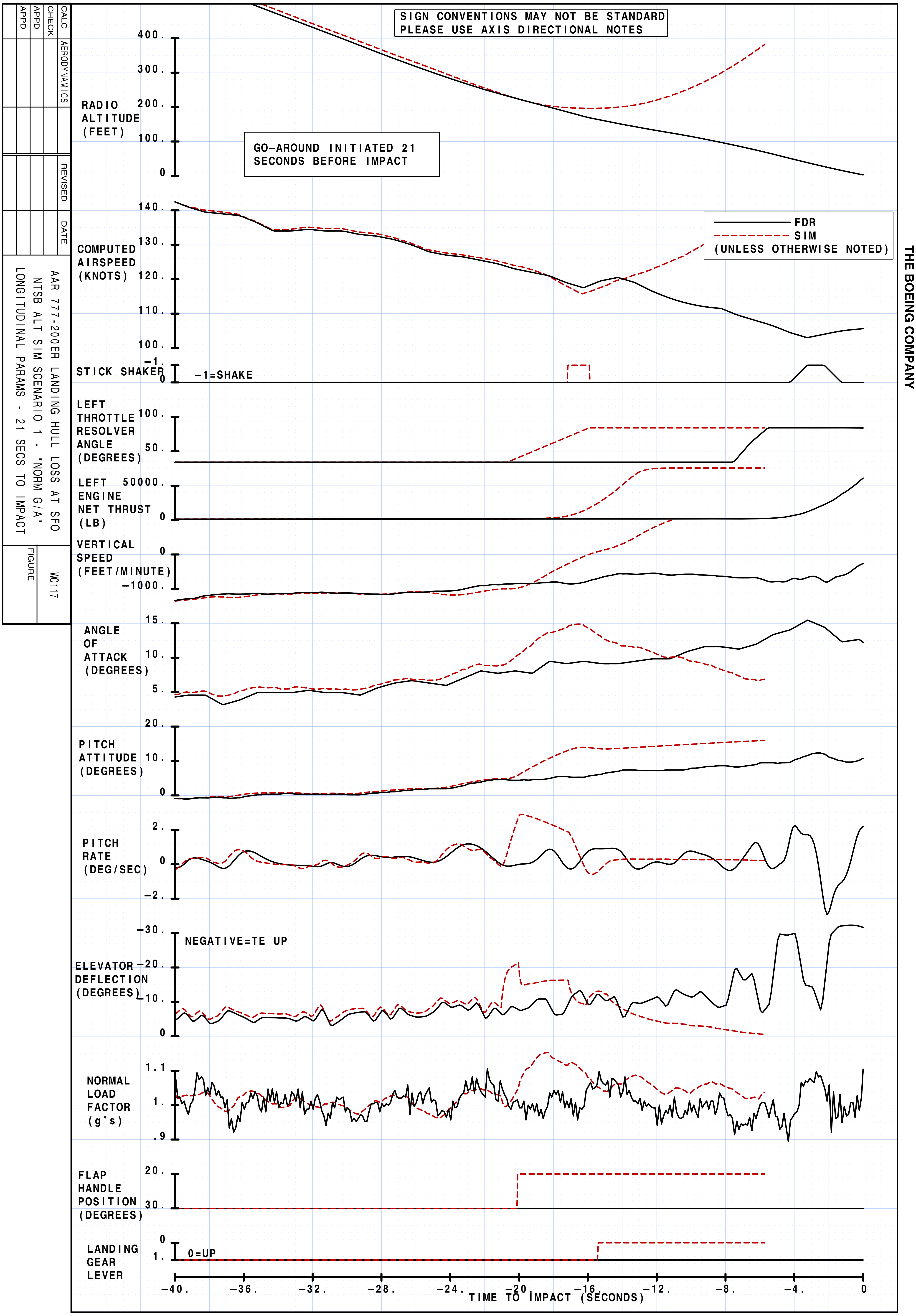


Figure A5.2: Normal Go-Around Simulation

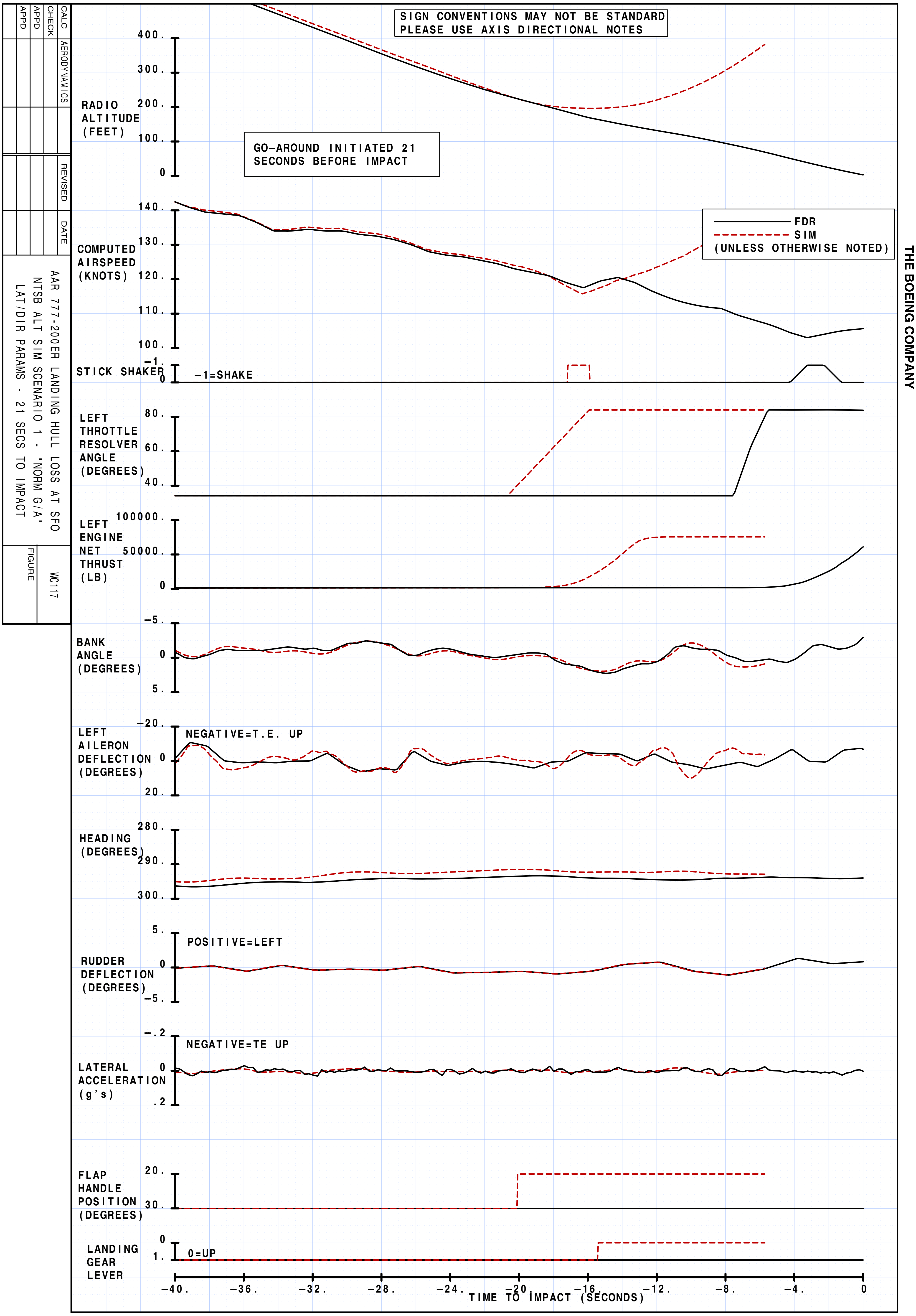


Figure A5.3: Normal Go-Around Simulation

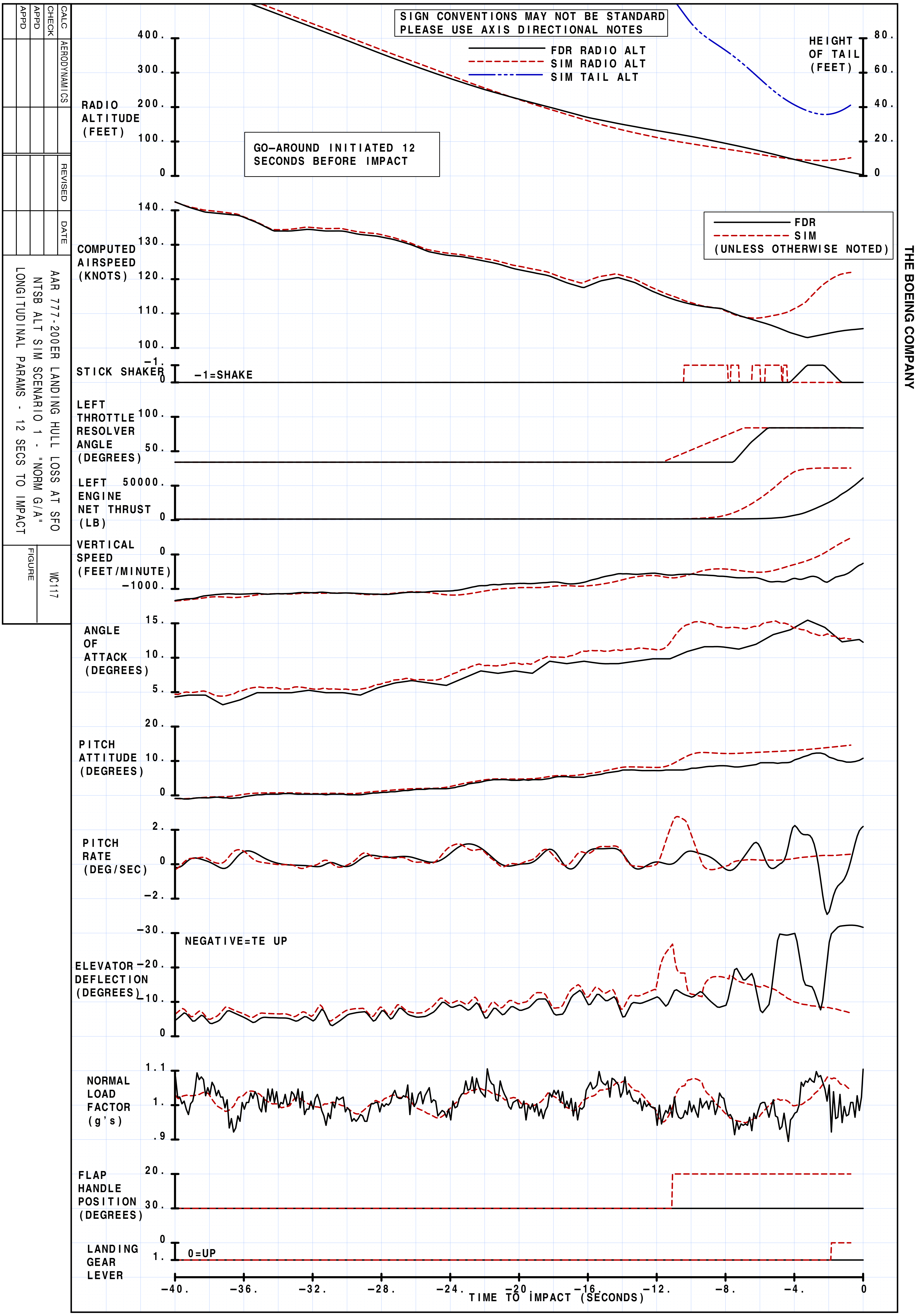


Figure A5.4: Normal Go-Around Simulation

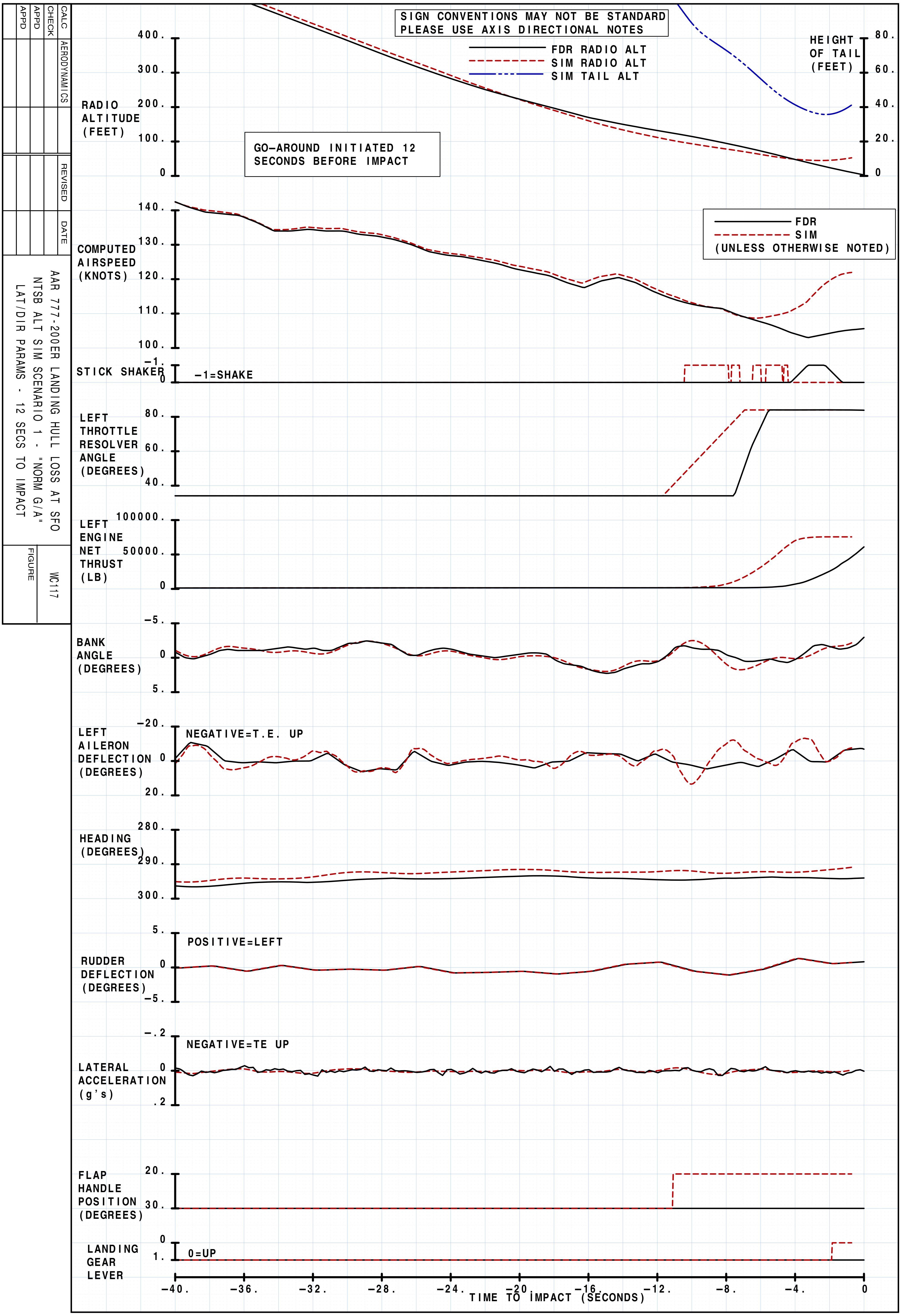


Figure A5.5: Normal Go-Around Simulation

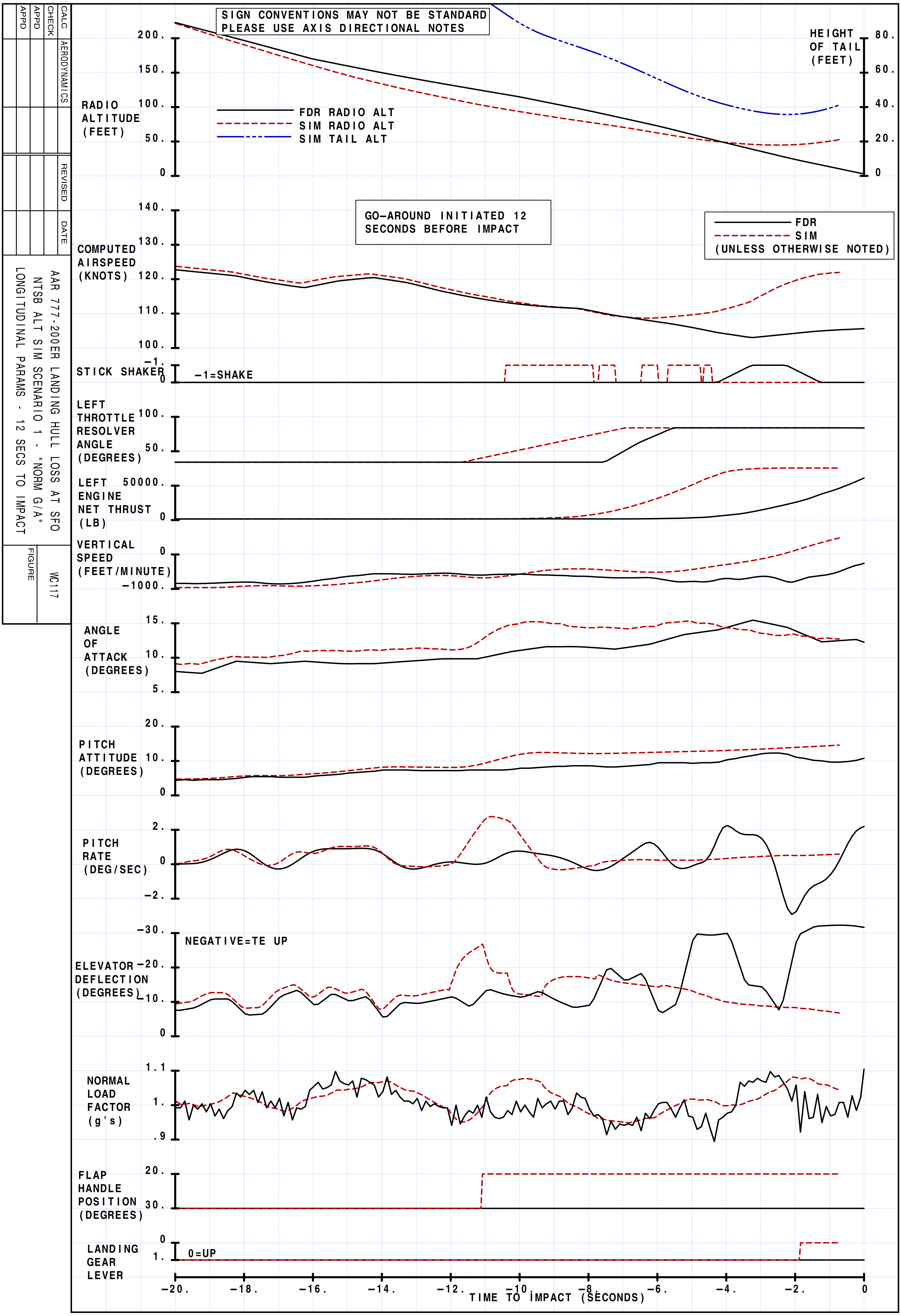


Figure A5.6: Normal Go-Around Simulation

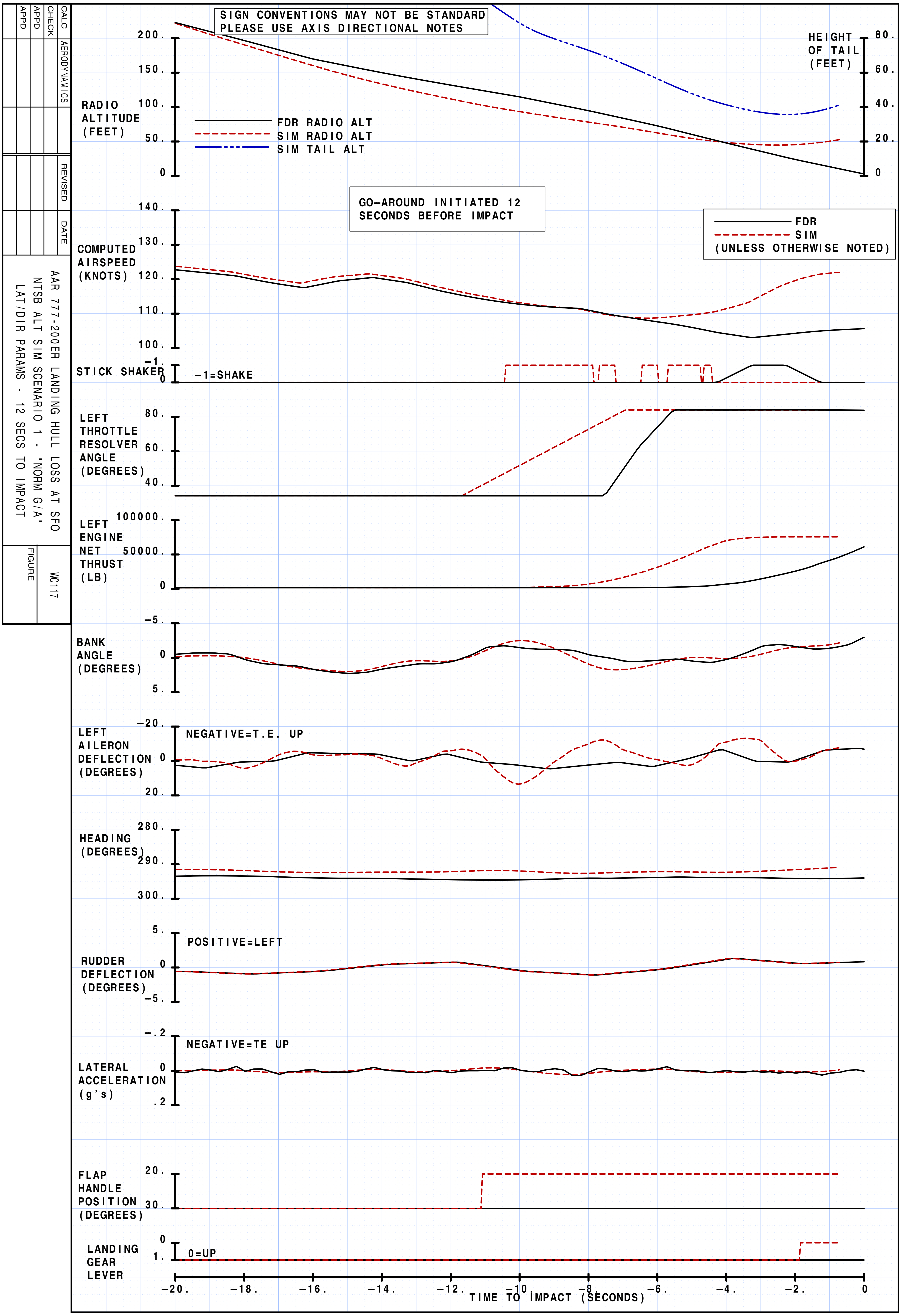


Figure A5.7: Event Go-Around Technique Simulation

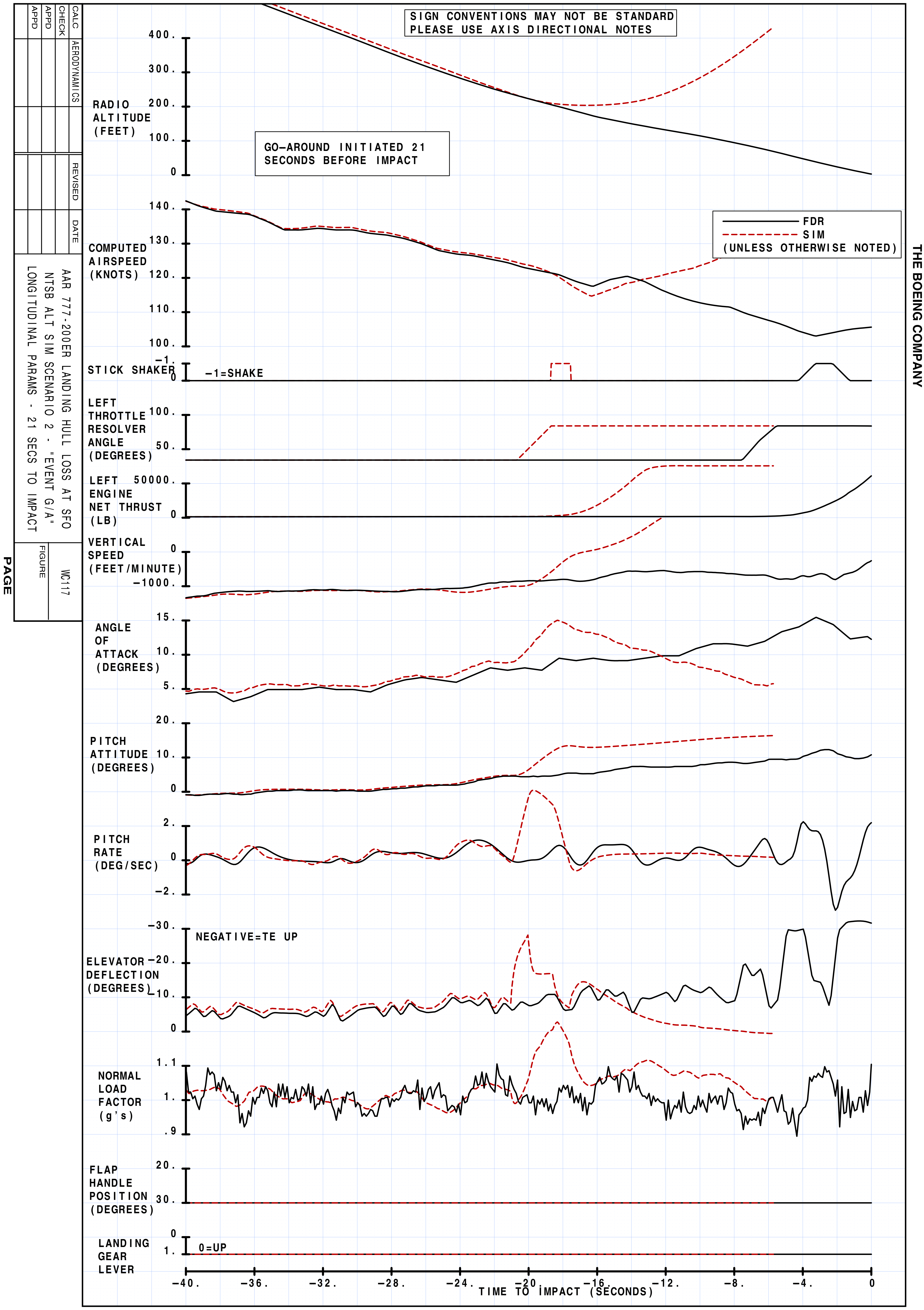


Figure A5.8: Event Go-Around Technique Simulation

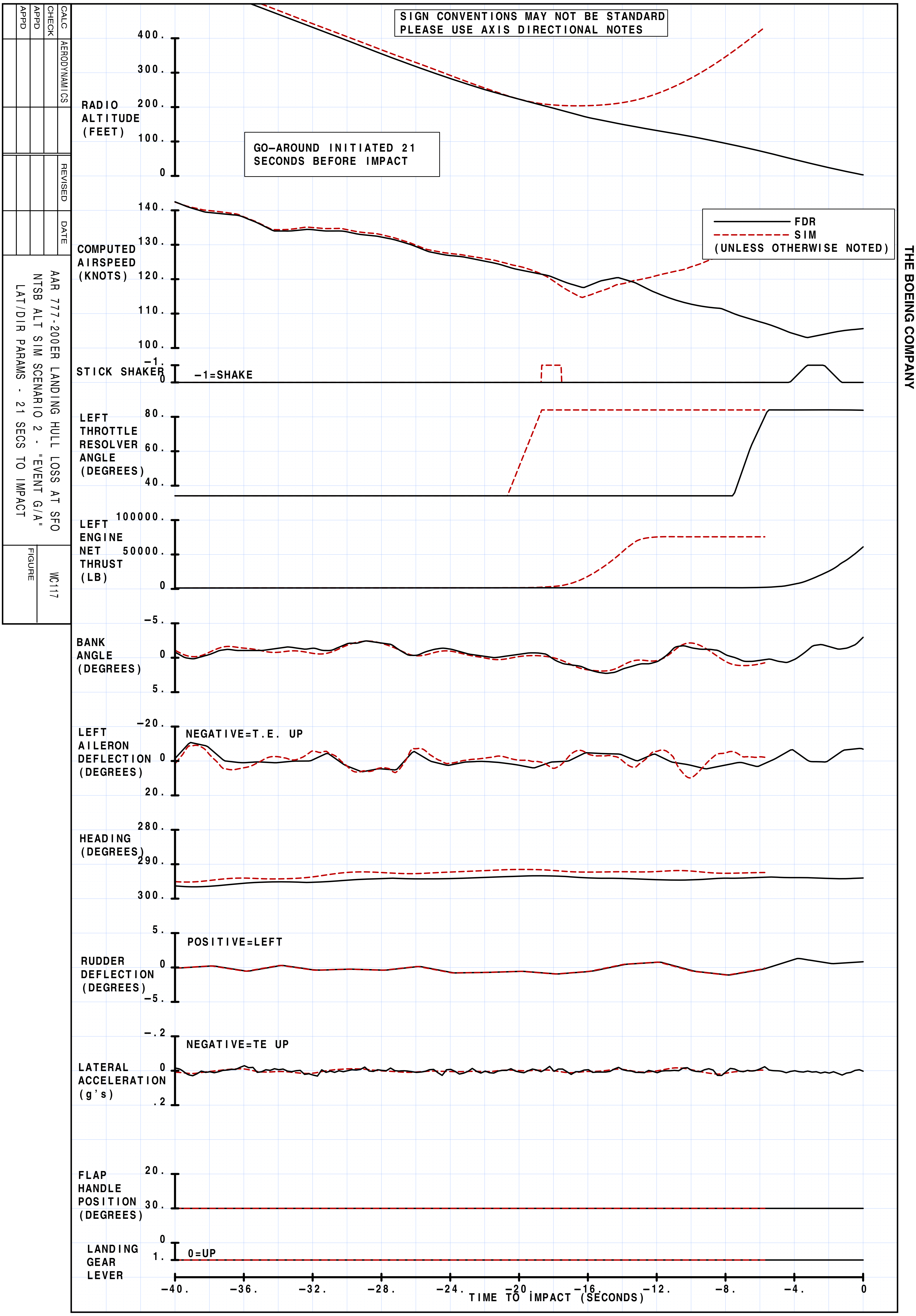


Figure A5.9: Event Go-Around Technique Simulation

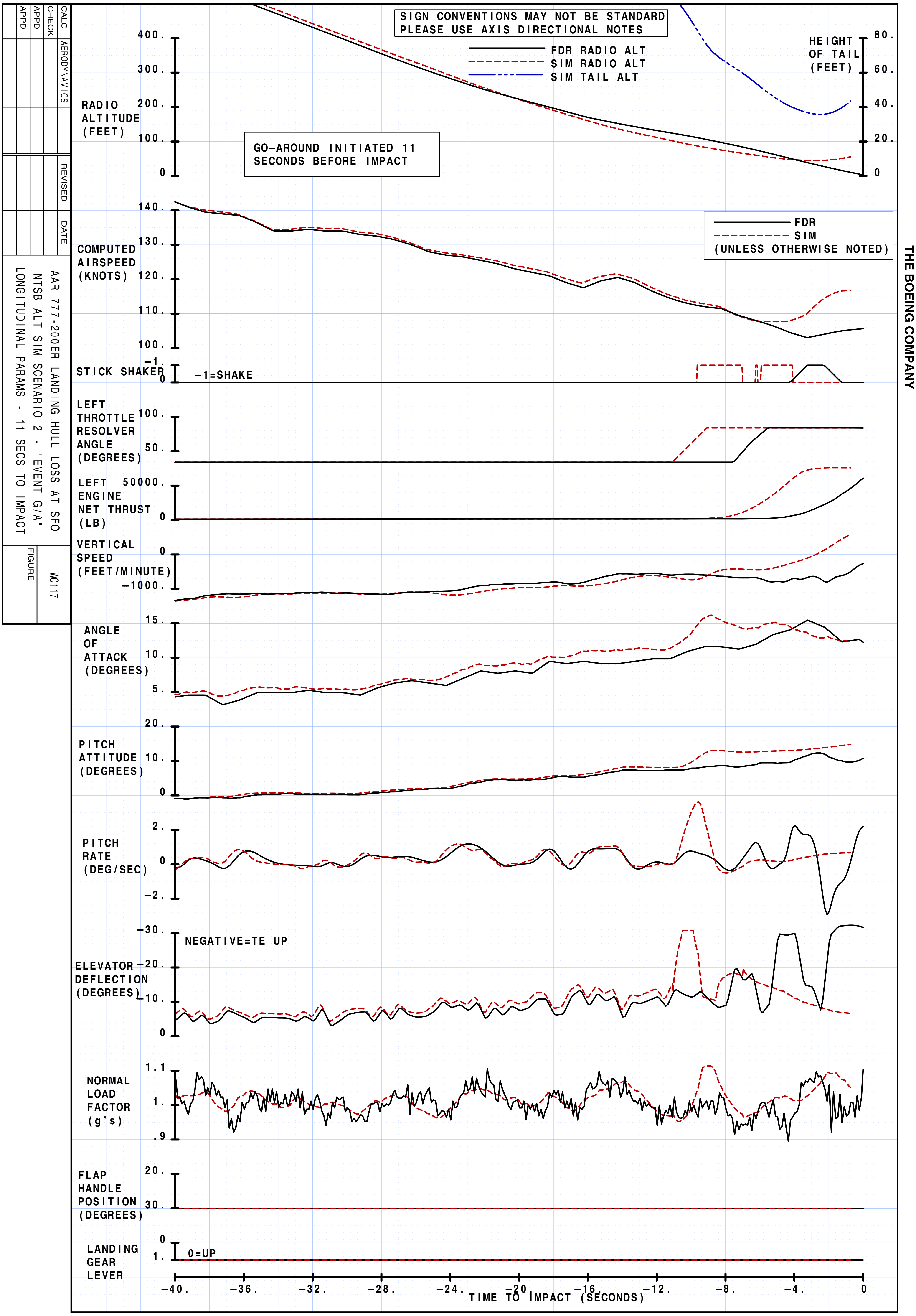


Figure A5.10: Event Go-Around Technique Simulation

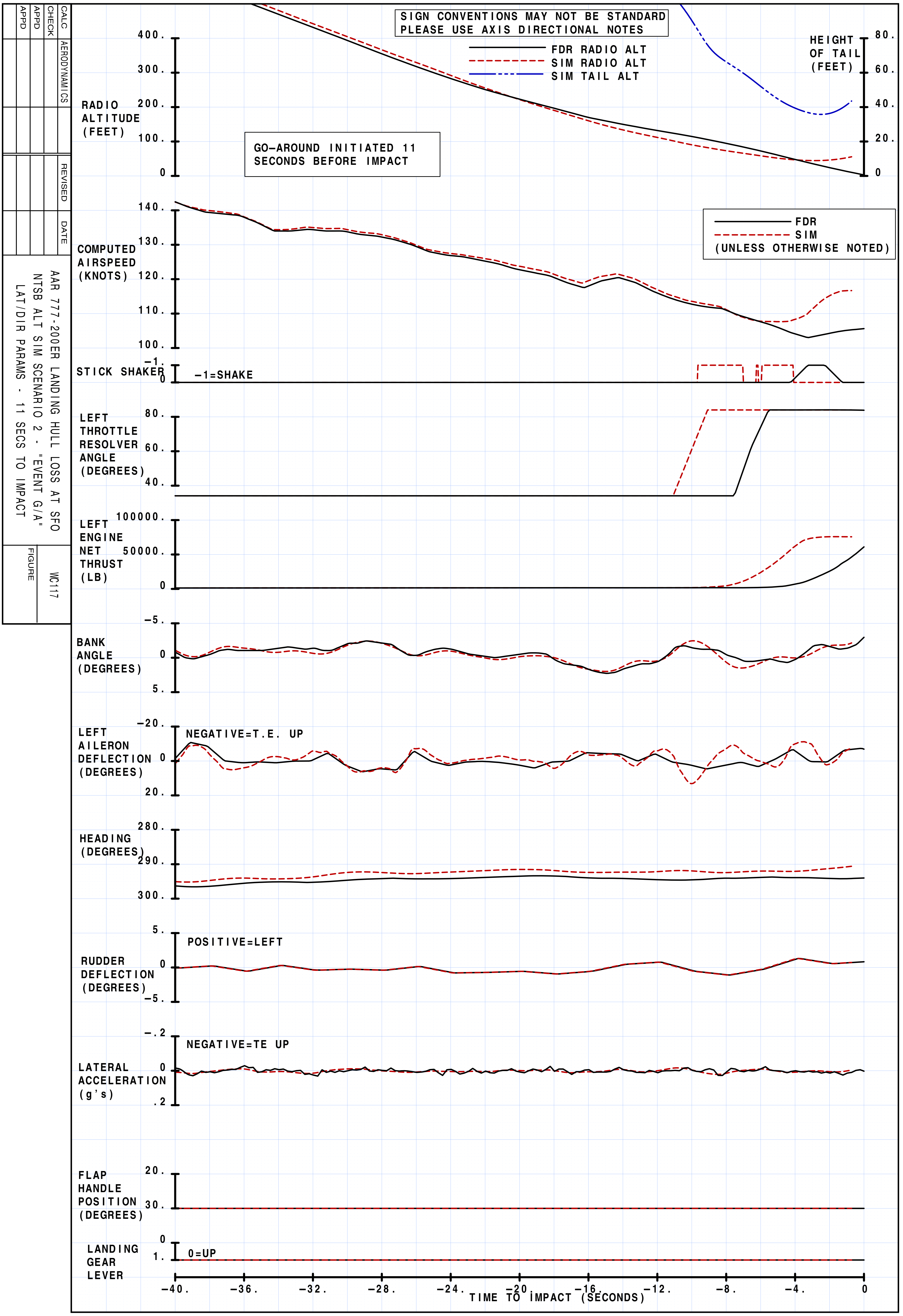


Figure A5.11: Event Go-Around Technique Simulation

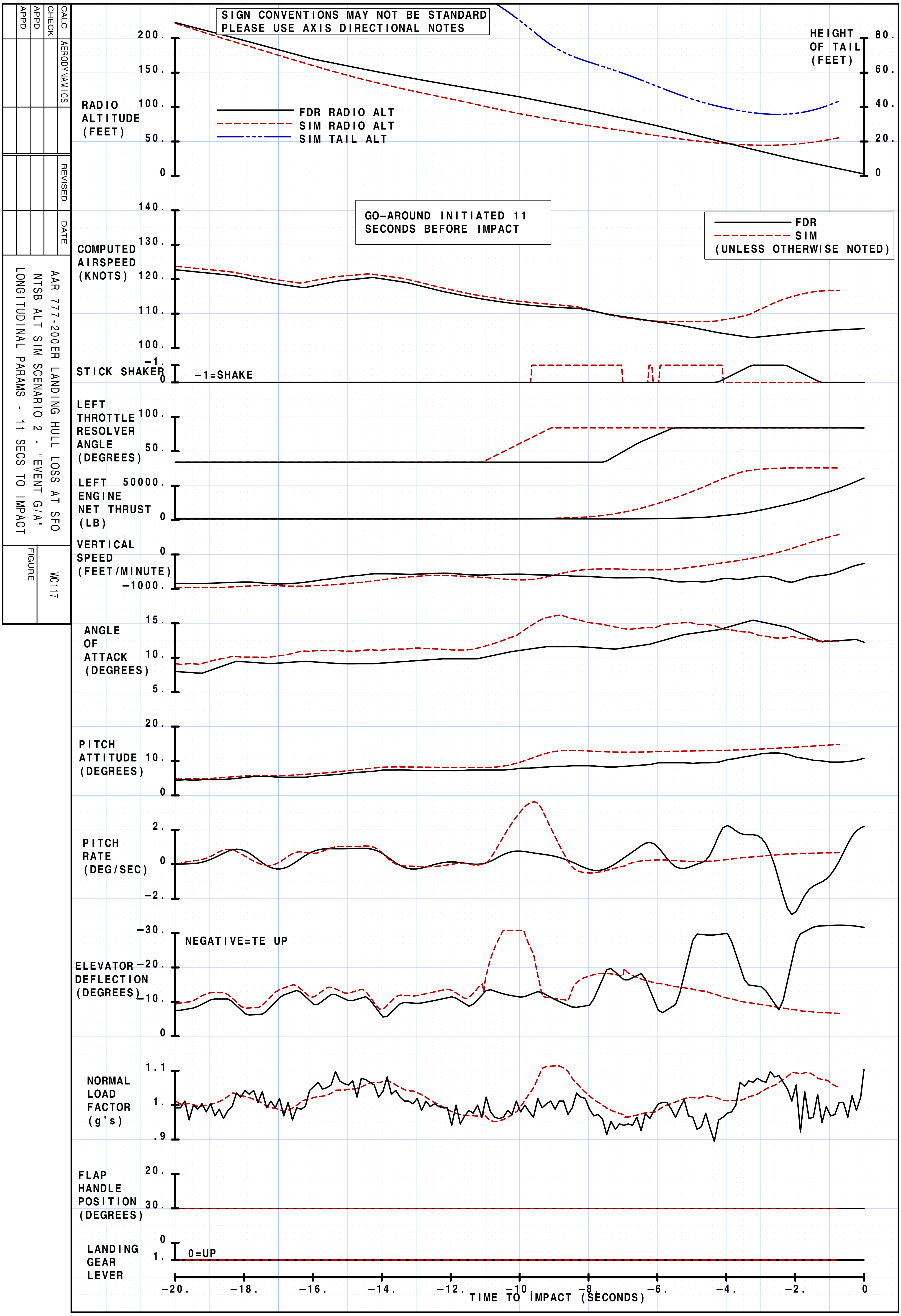


Figure A5.12: Event Go-Around Technique Simulation

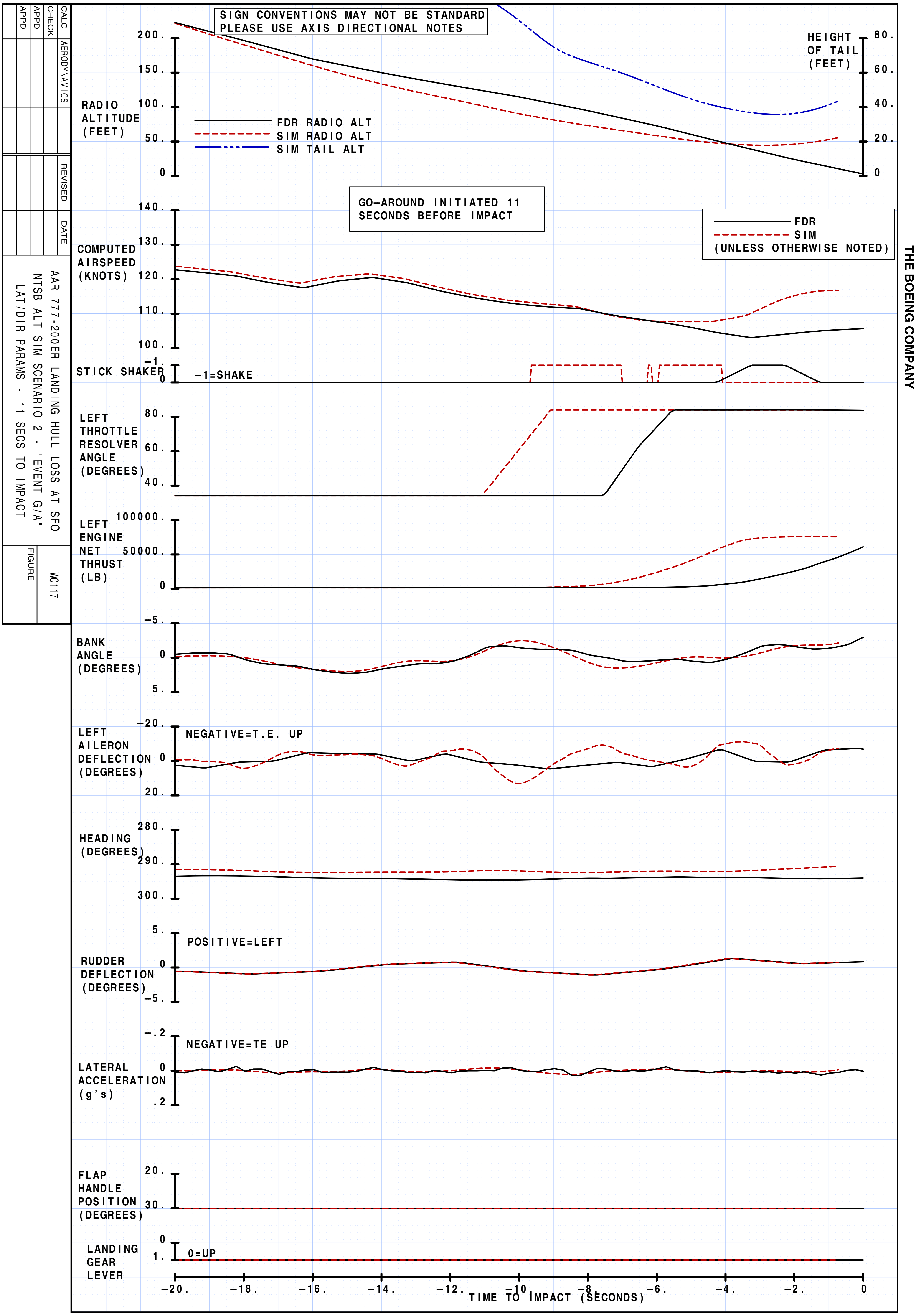


Figure A5.13: Hybrid 1 Go-Around Technique Simulation

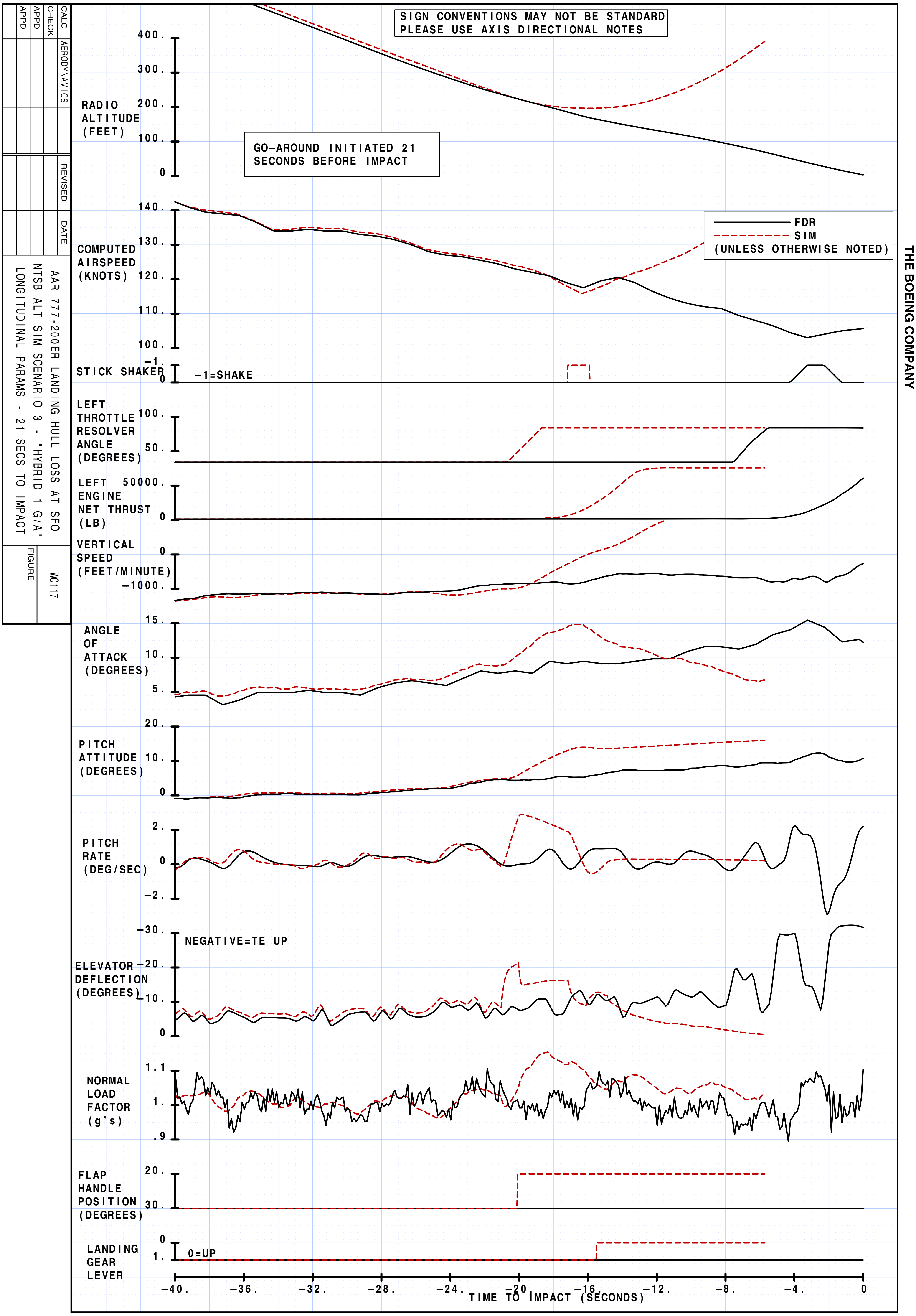


Figure A5.14: Hybrid 1 Go-Around Technique Simulation

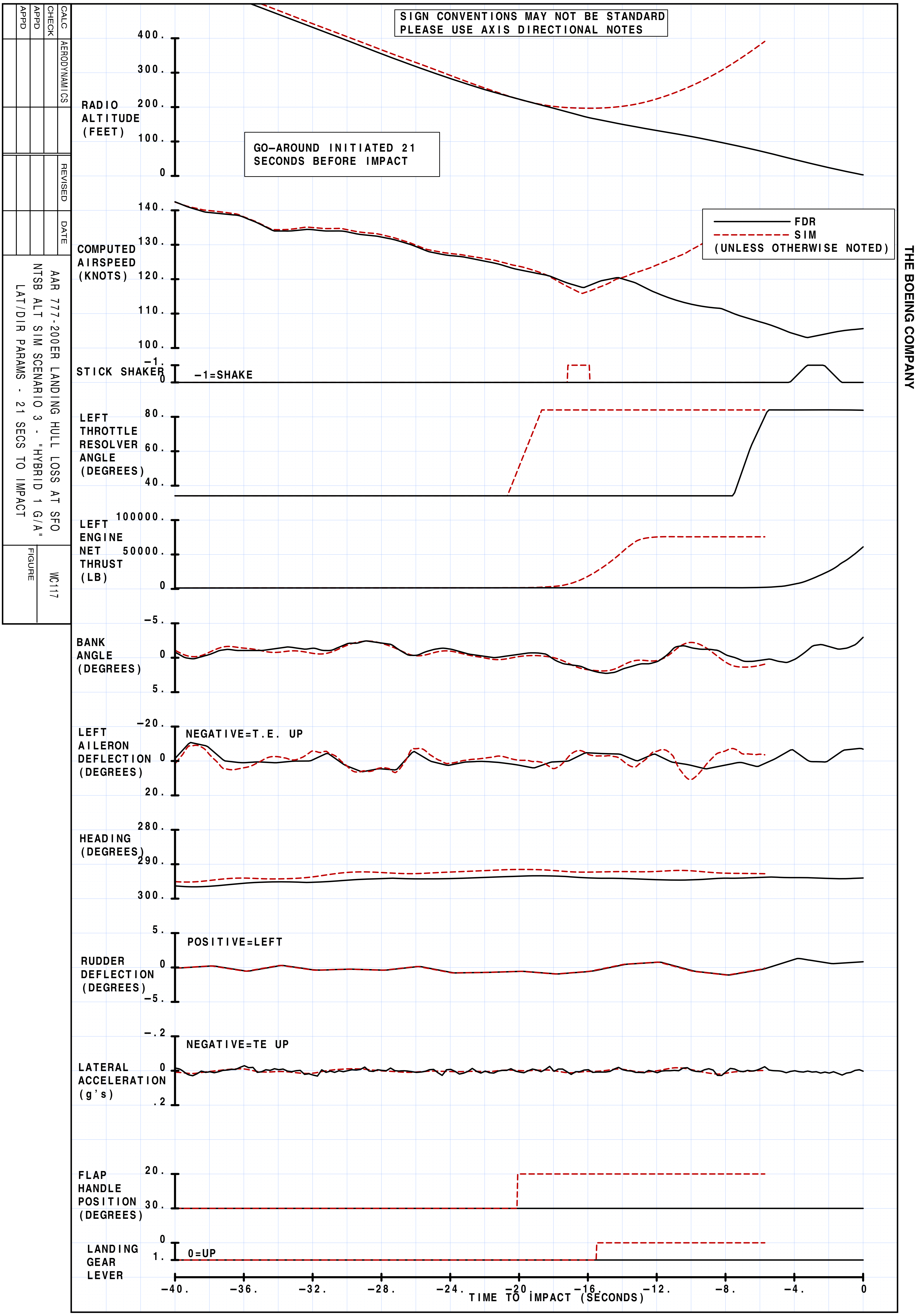


Figure A5.15: Hybrid 1 Go-Around Technique Simulation

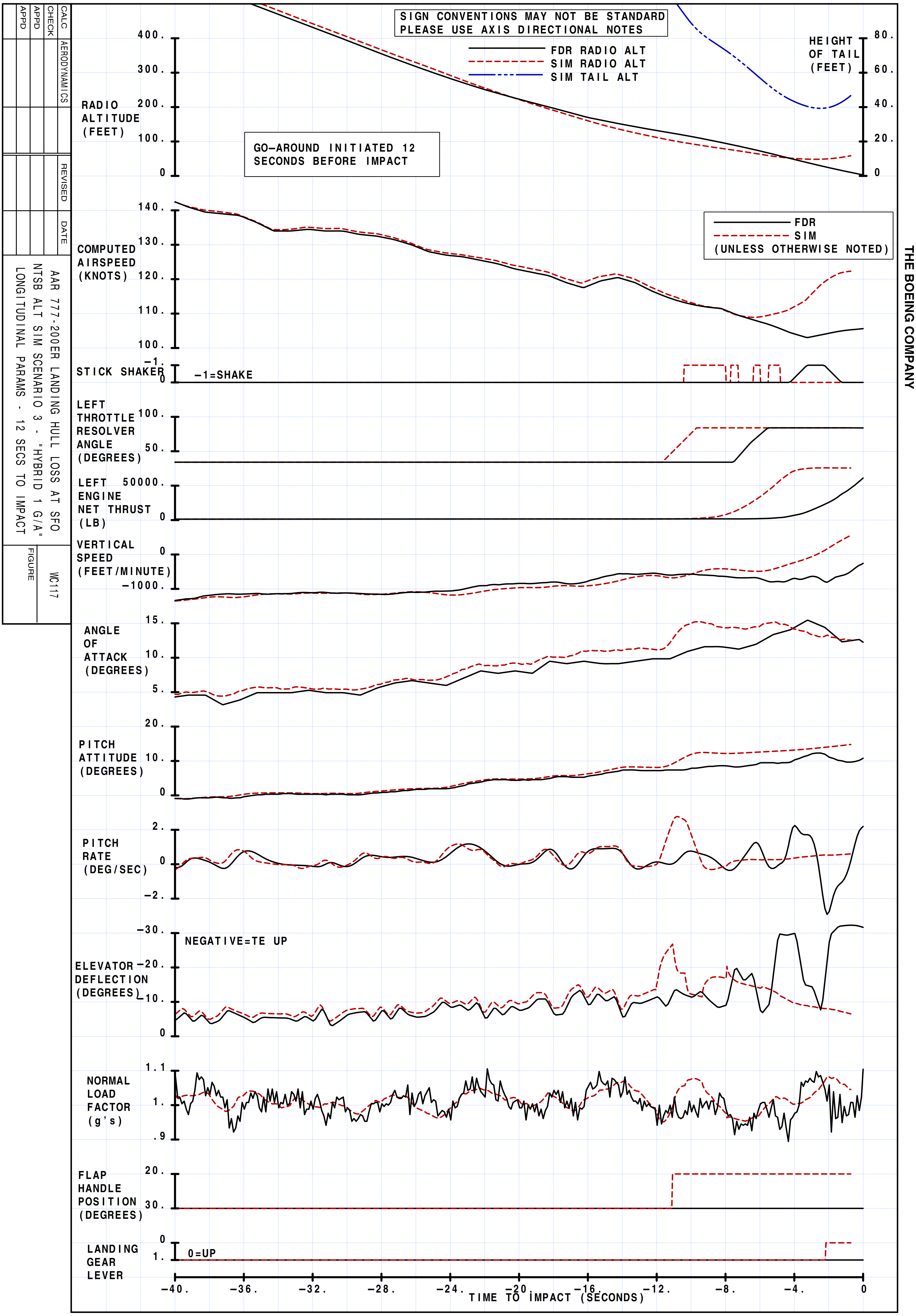


Figure A5.16: Hybrid 1 Go-Around Technique Simulation

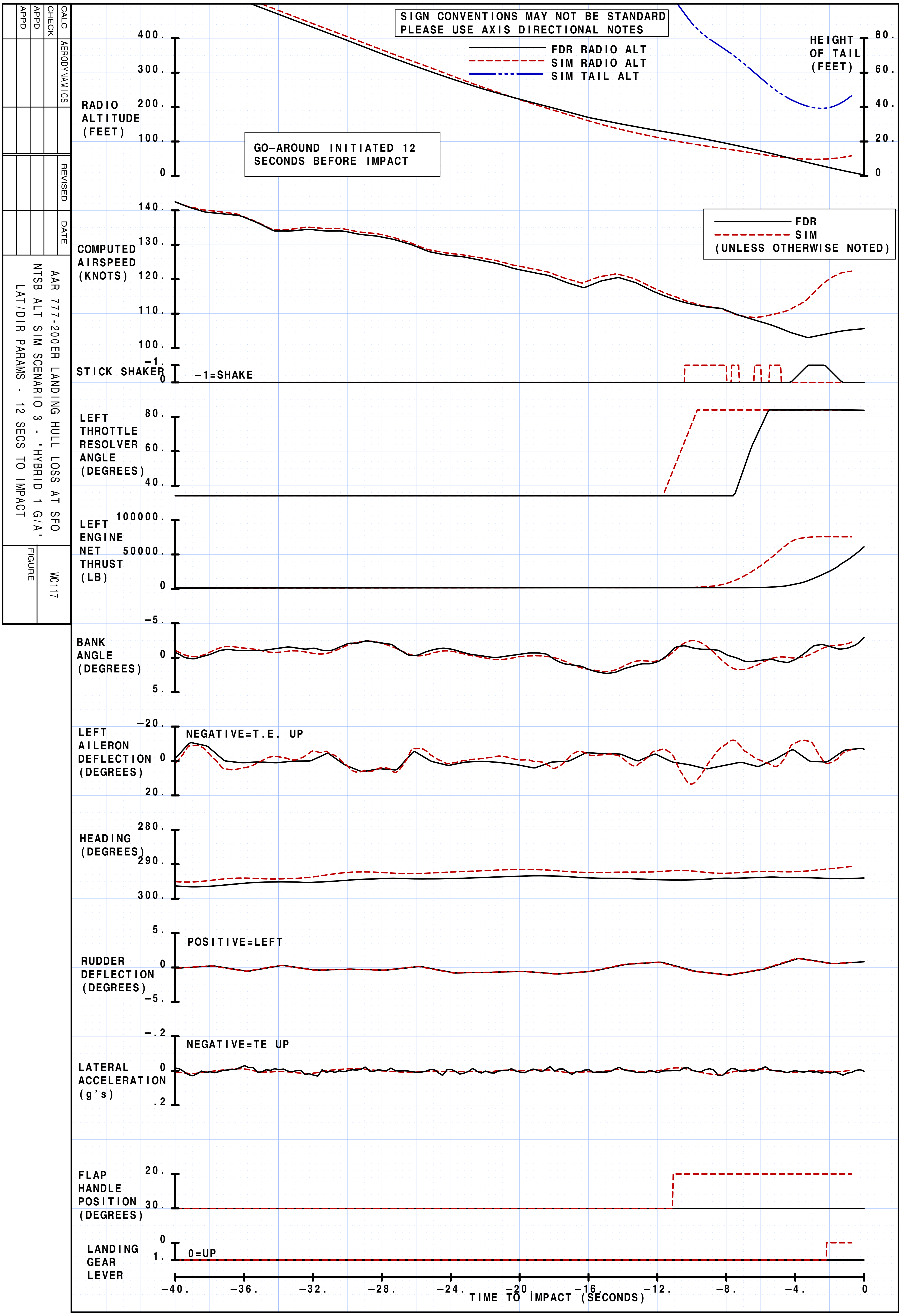


Figure A5.17: Hybrid 1 Go-Around Technique Simulation

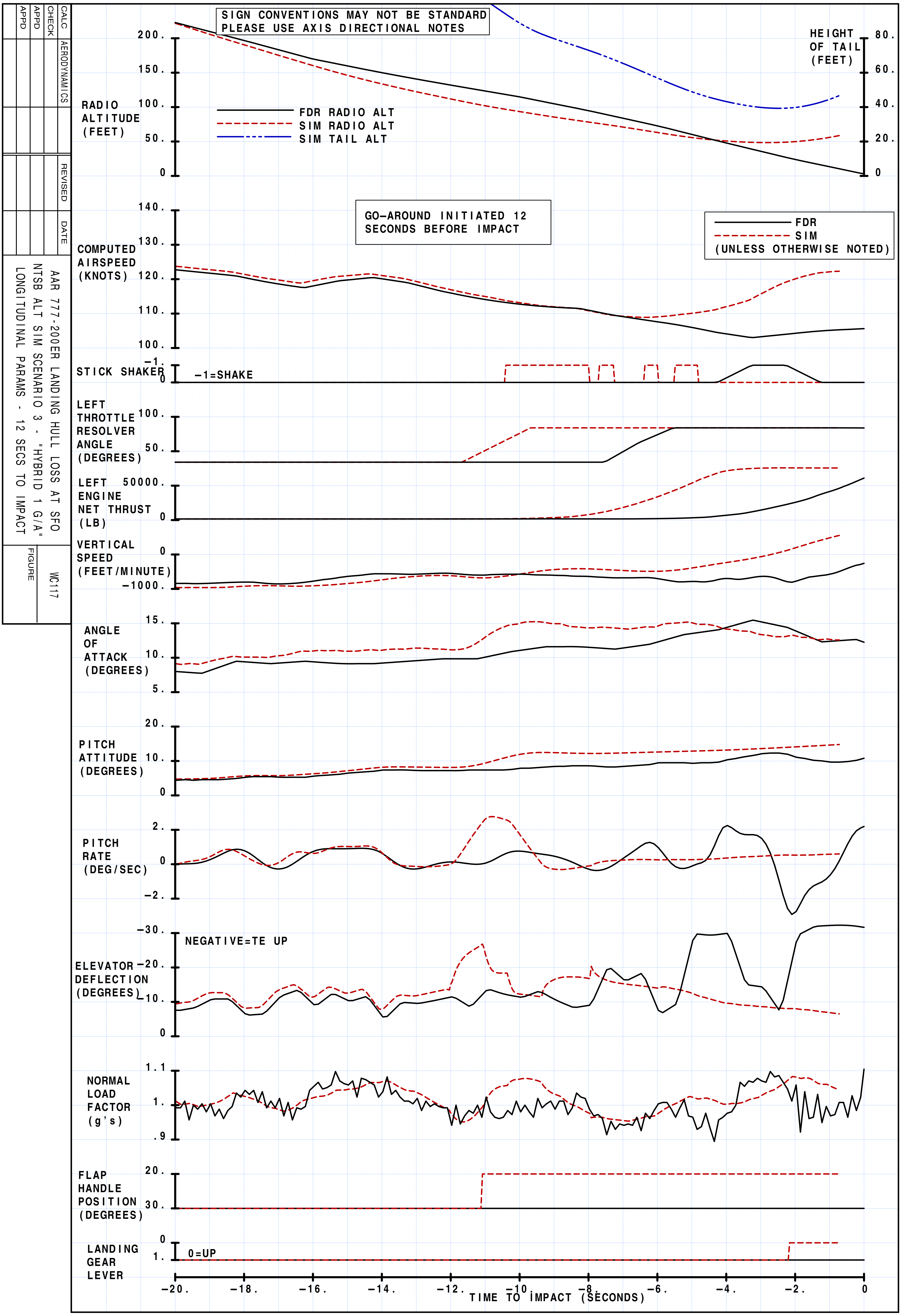


Figure A5.18: Hybrid 1 Go-Around Technique Simulation

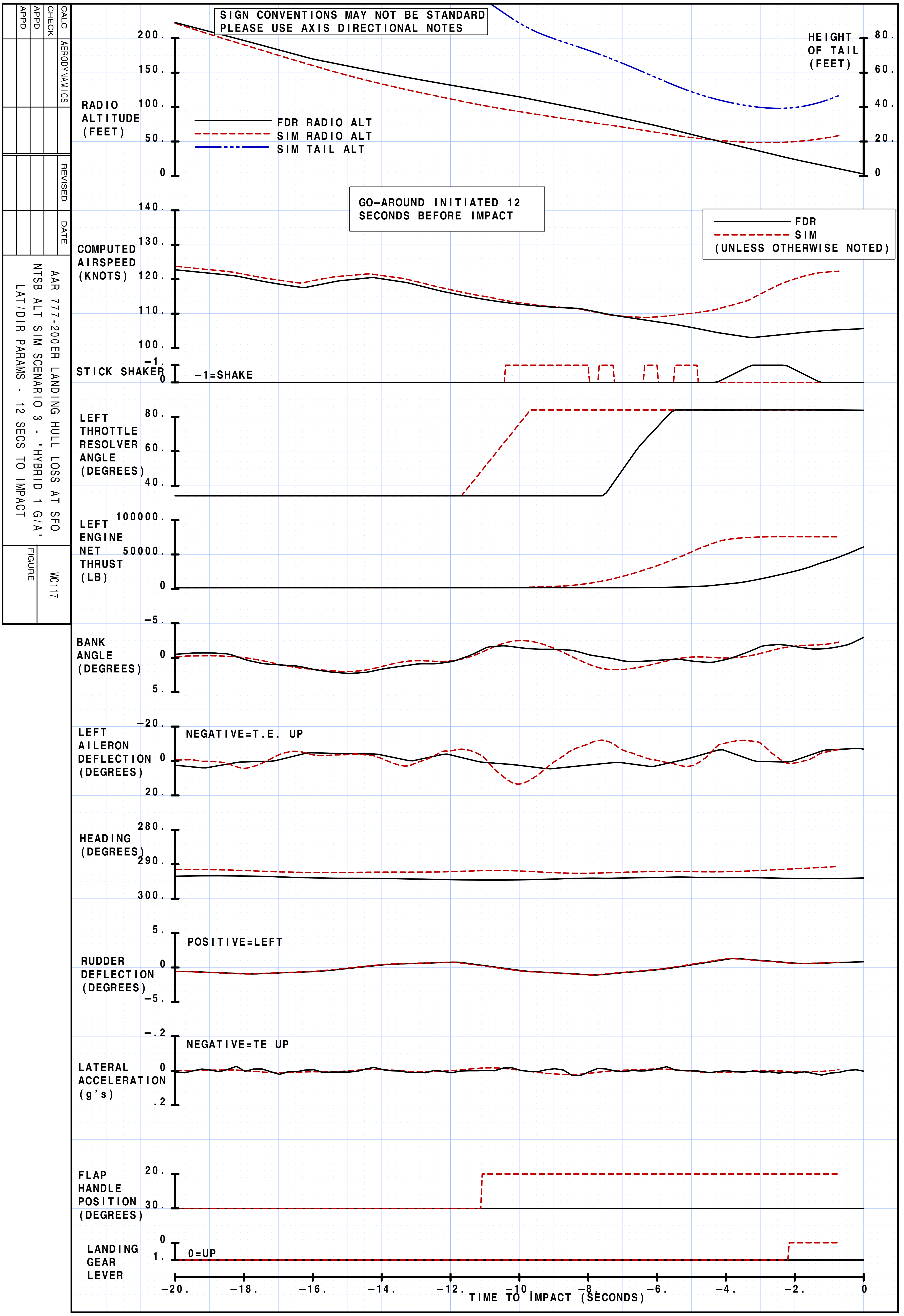


Figure A5.19: Hybrid 2 Go-Around Technique Simulation

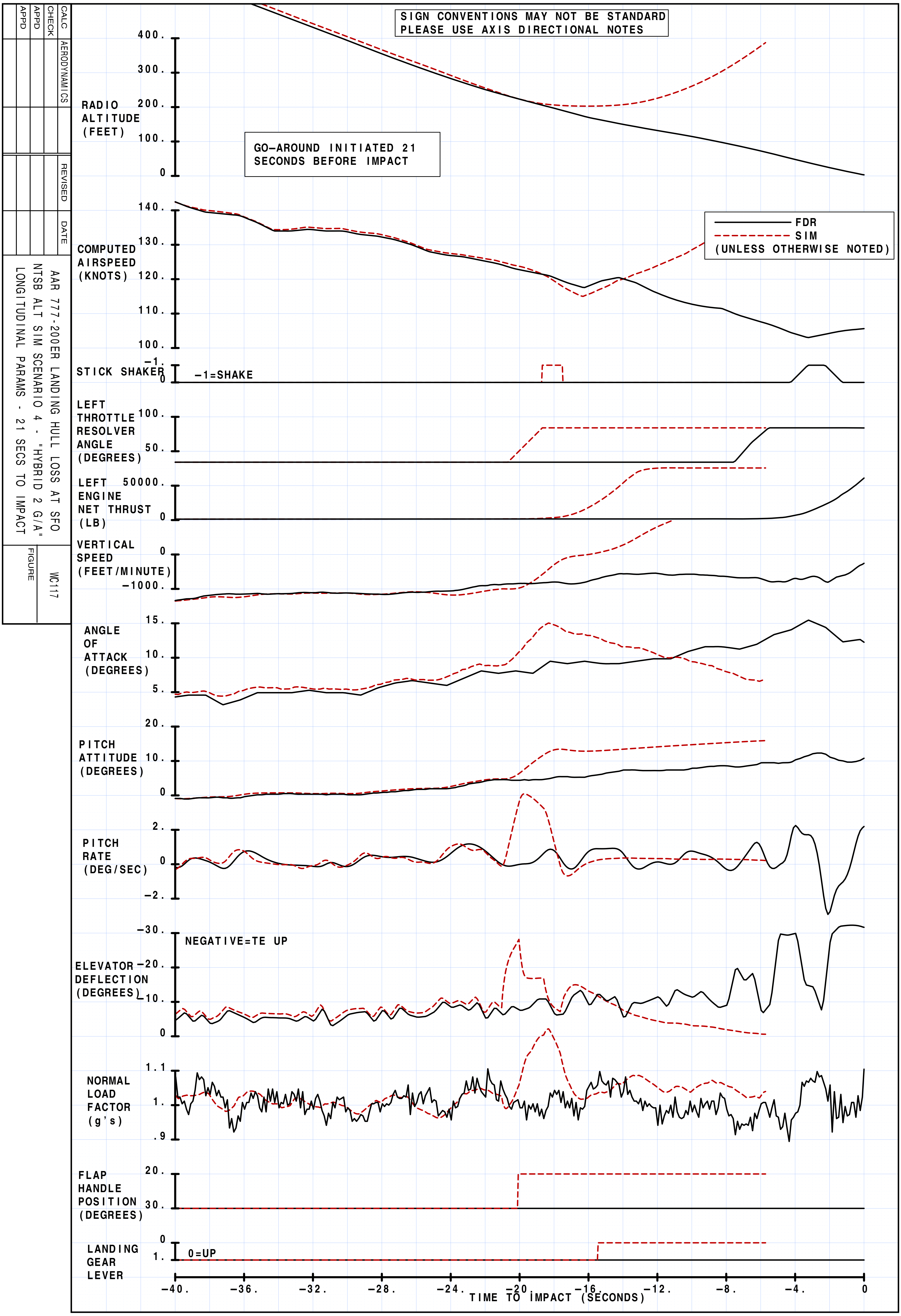


Figure A5.20: Hybrid 2 Go-Around Technique Simulation

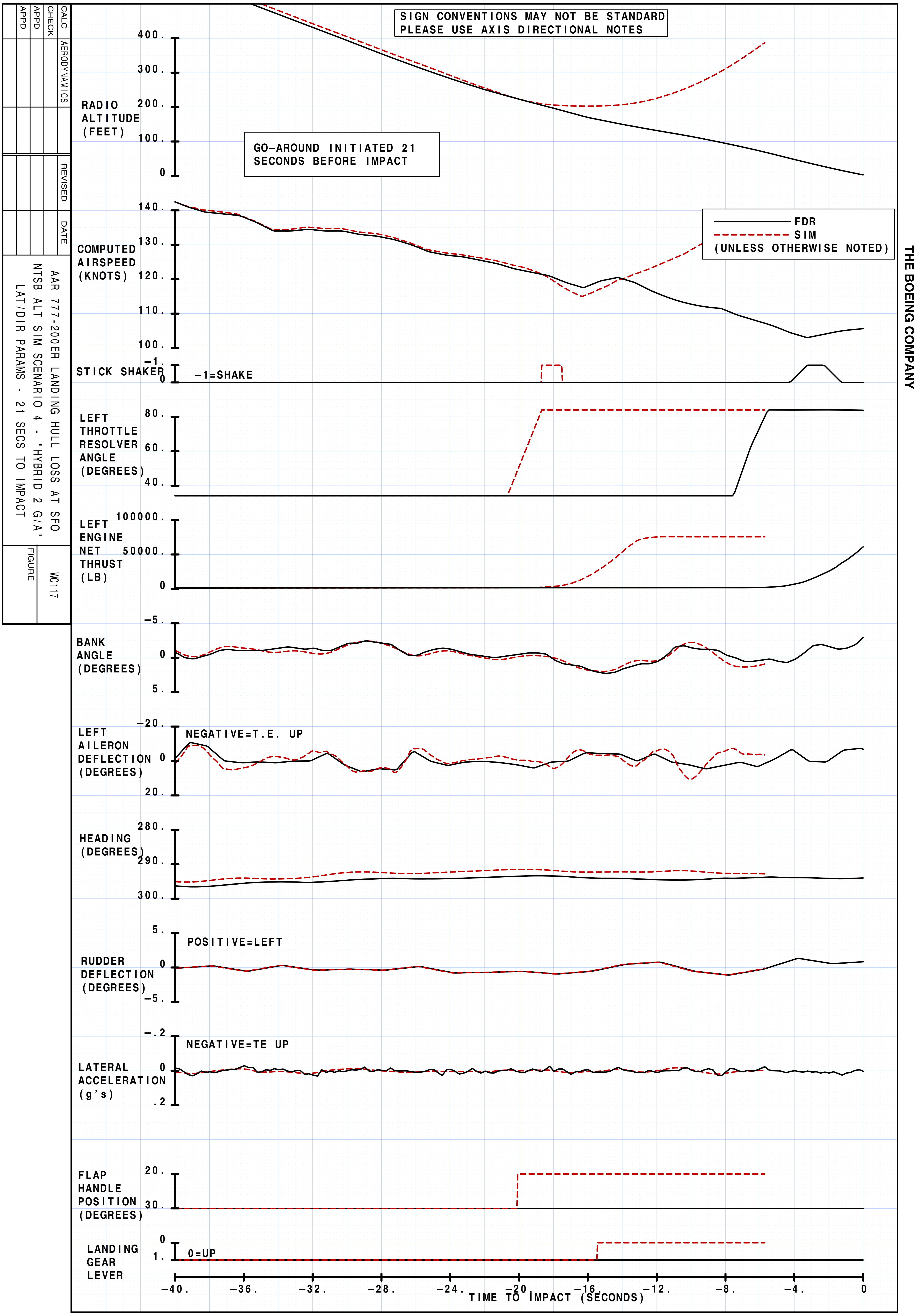


Figure A5.21: Hybrid 2 Go-Around Technique Simulation

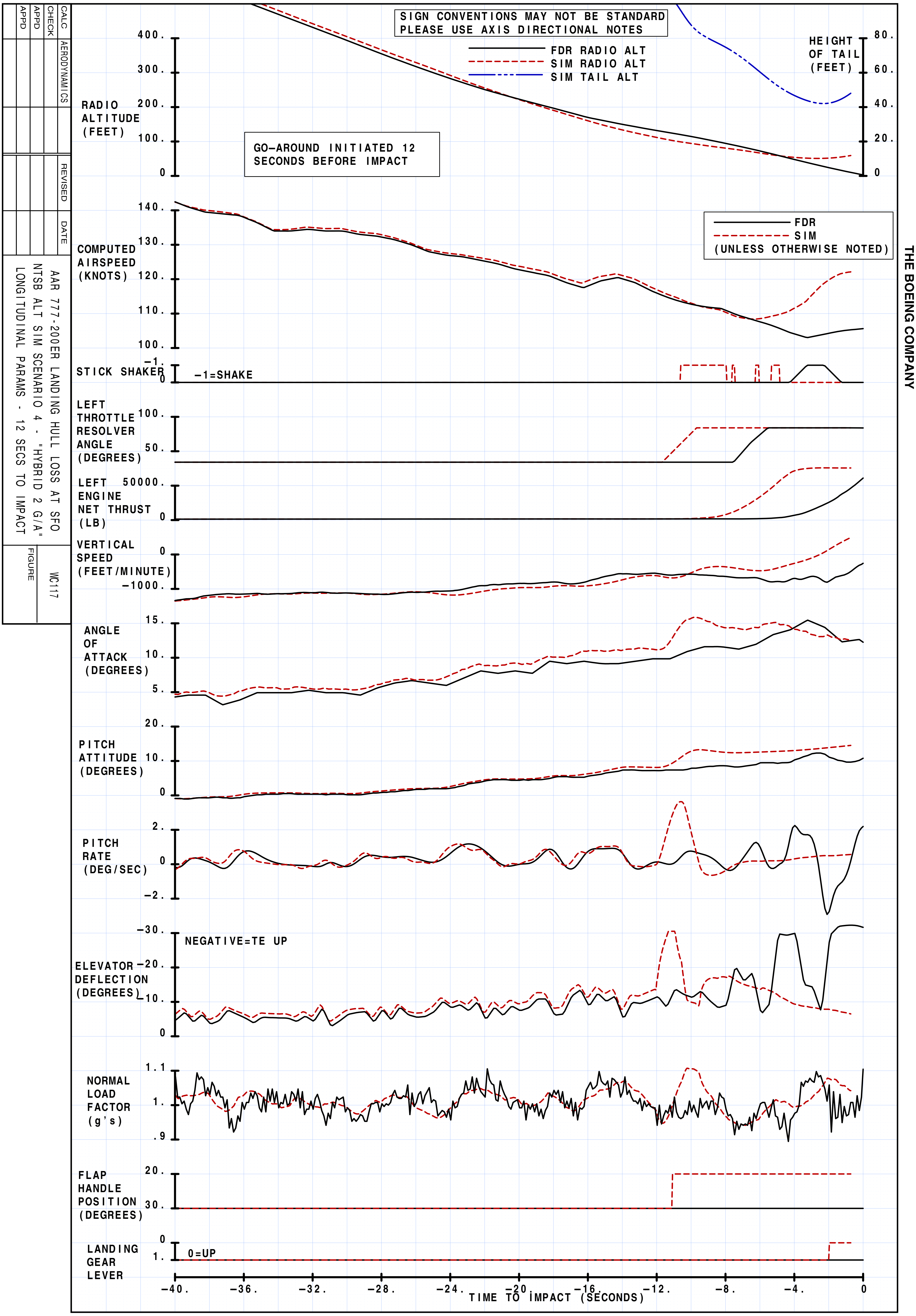


Figure A5.22: Hybrid 2 Go-Around Technique Simulation

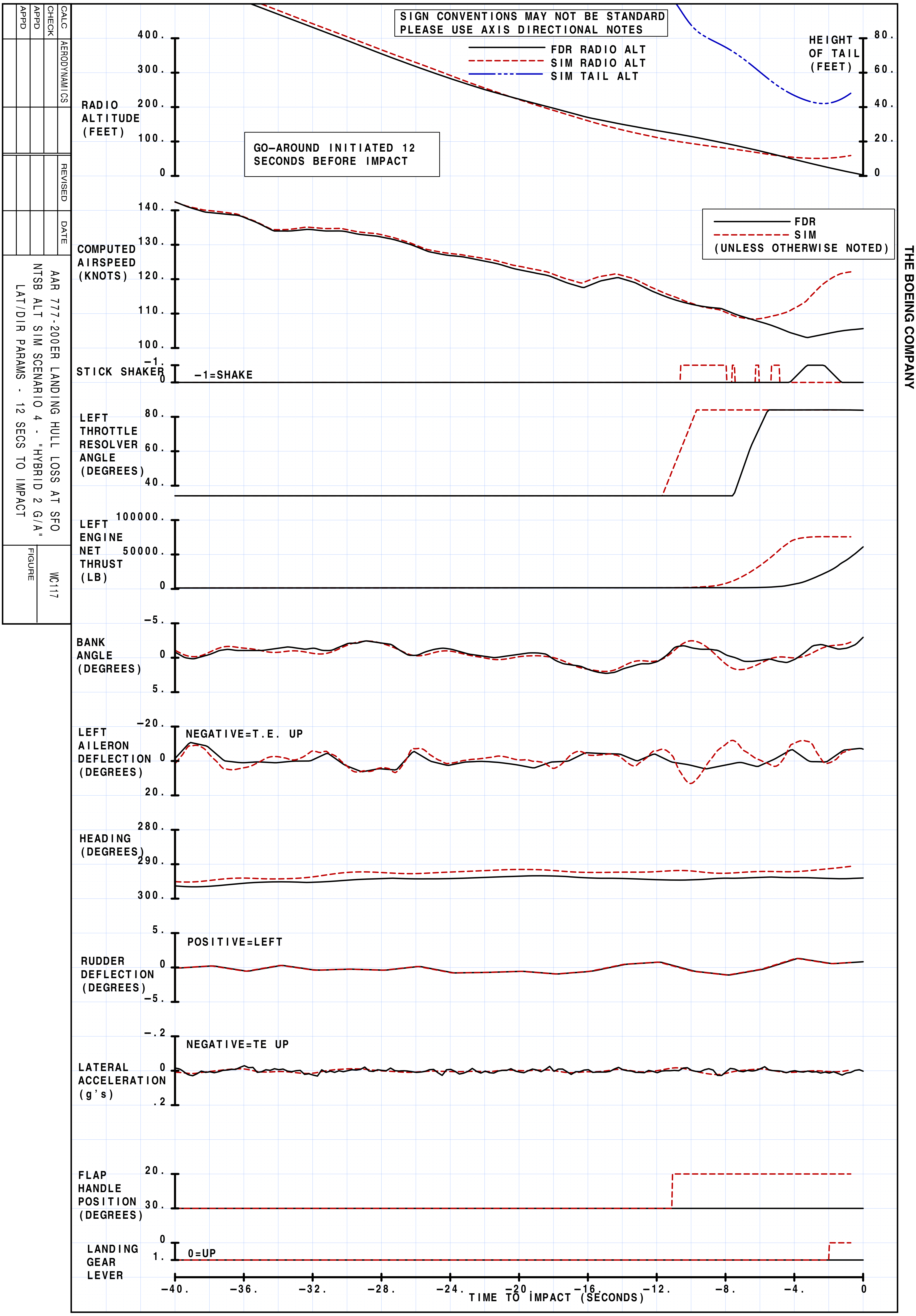


Figure A5.23: Hybrid 2 Go-Around Technique Simulation

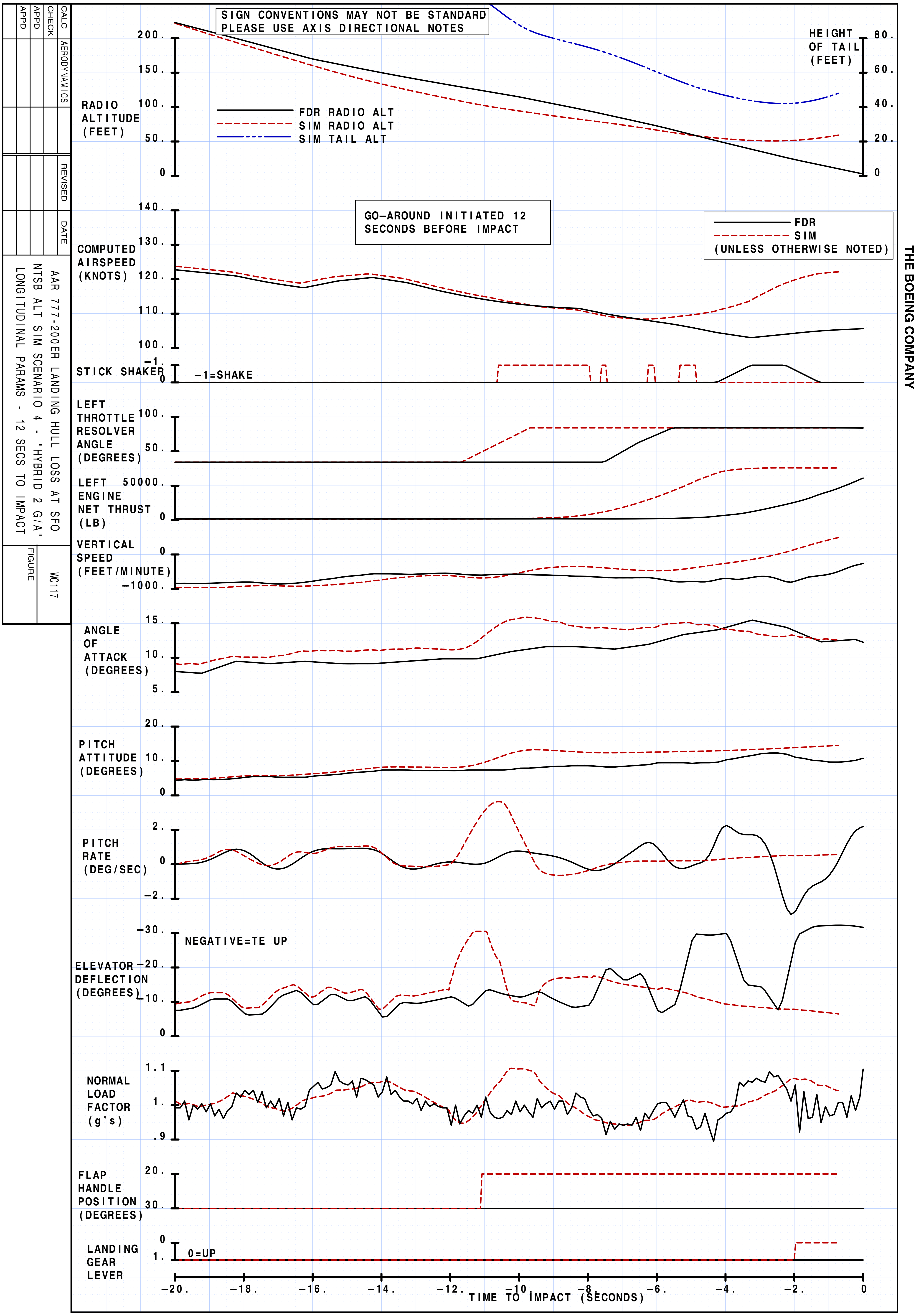
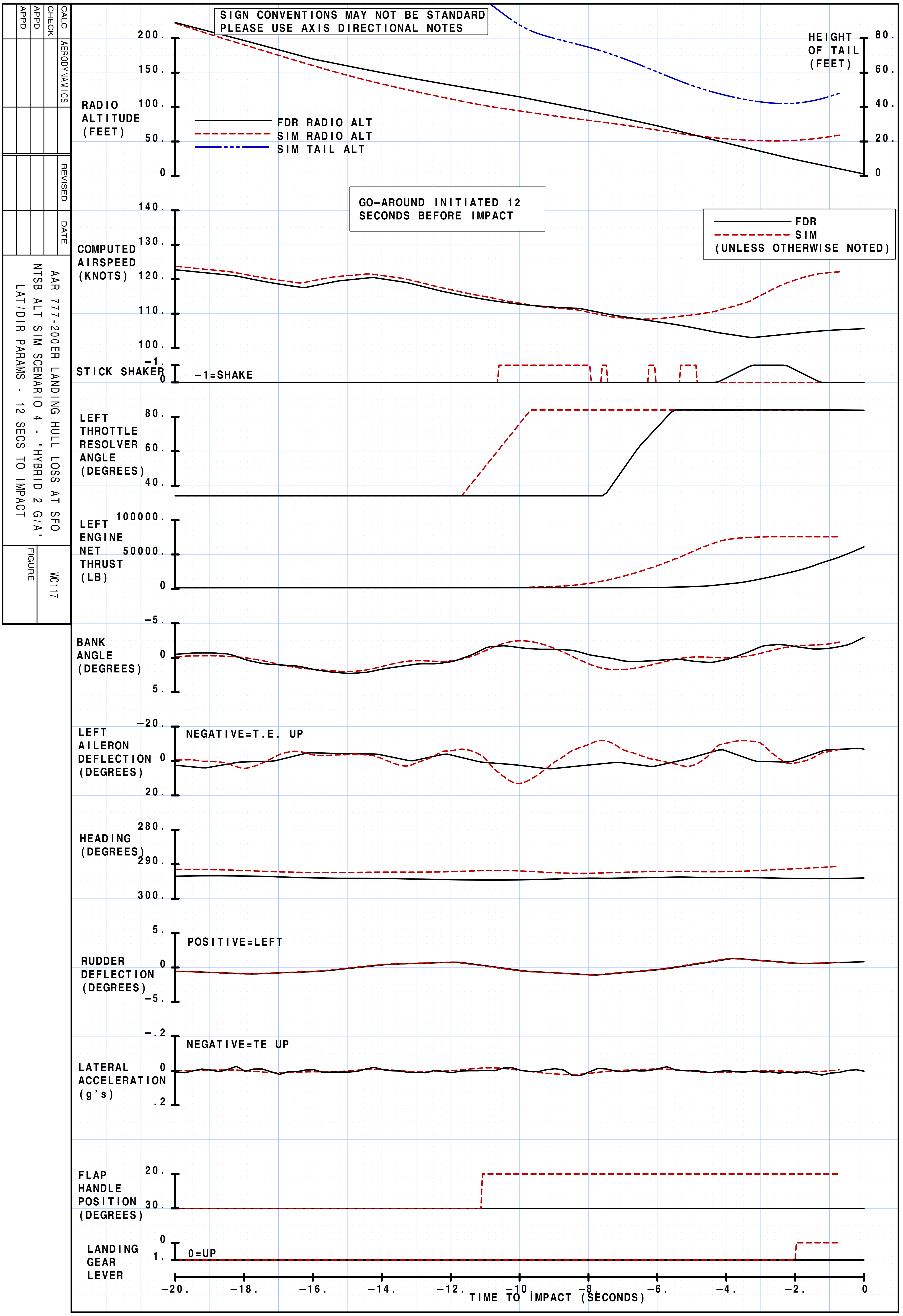


Figure A5.24: Hybrid 2 Go-Around Technique Simulation



Attachment 6: Stabilized Approach Criteria

Stabilized Approach Recommendations

Maintaining a stable speed, descent rate, and vertical/lateral flight path in landing configuration is commonly referred to as the stabilized approach concept.

Any significant deviation from planned flight path, airspeed, or descent rate should be announced. The decision to execute a go-around is no indication of poor performance.

Note: Do not attempt to land from an unstable approach.

Recommended Elements of a Stabilized Approach

The following recommendations are consistent with criteria developed by the Flight Safety Foundation.

All approaches should be stabilized by 1,000 feet AFE in instrument meteorological conditions (IMC) and by 500 feet AFE in visual meteorological conditions (VMC). An approach is considered stabilized when all of the following criteria are met:

- the airplane is on the correct flight path
- only small changes in heading and pitch are required to maintain the correct flight path
- the airplane should be at approach speed. Deviations of +10 knots to – 5 knots are acceptable if the airspeed is trending toward approach speed
- the airplane is in the correct landing configuration
- sink rate is no greater than 1,000 fpm; if an approach requires a sink rate greater than 1,000 fpm, a special briefing should be conducted

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- thrust setting is appropriate for the airplane configuration
- all briefings and checklists have been conducted.

Specific types of approaches are stabilized if they also fulfill the following:

- ILS approaches should be flown within one dot of the glide slope and localizer, or within the expanded localizer scale
- during a circling approach, wings should be level on final when the airplane reaches 300 feet AFE.

Unique approach procedures or abnormal conditions requiring a deviation from the above elements of a stabilized approach require a special briefing.

Note: An approach that becomes unstabilized below 1,000 feet AFE in IMC or below 500 feet AFE in VMC requires an immediate go-around.

These conditions should be maintained throughout the rest of the approach for it to be considered a stabilized approach. If the above criteria cannot be established and maintained until approaching the flare, initiate a go-around.

At 100 feet HAT for all visual approaches, the airplane should be positioned so the flight deck is within, and tracking to remain within, the lateral confines of the runway edges extended.

As the airplane crosses the runway threshold it should be:

- stabilized on approach airspeed to within + 10 knots until arresting descent rate at flare
- on a stabilized flight path using normal maneuvering
- positioned to make a normal landing in the touchdown zone (the first 3,000 feet or first third of the runway, whichever is less).

Initiate a go-around if the above criteria cannot be maintained.

Maneuvering (including runway changes and circling)

When maneuvering below 500 feet, be cautious of the following:

- descent rate change to acquire glide path
- lateral displacement from the runway centerline
- tailwind or crosswind components
- runway length available.

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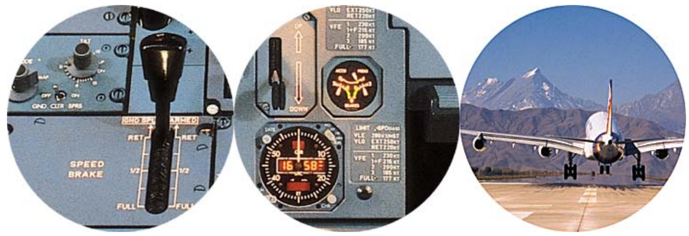

Flight Operations Briefing Notes

Approach and Landing

FSF ALAR Task Force Conclusions and Recommendations

I Introduction

This summary presents the conclusions and recommendations of the international Approach-and-Landing Accident Reduction (ALAR) Task Force led by the Flight Safety Foundation (FSF).

II Background

The FSF ALAR Task Force was created in 1996 as another phase of the Controlled Flight Into Terrain (CFIT) accident reduction program launched in the early 1990s.

The FSF ALAR Task Force collected and analyzed data related to a significant set of approach-and-landing accidents, including those resulting in controlled flight into terrain CFIT).

The Task Force developed conclusions and recommendations for practices that would improve safety in approach-and-landing, in the following domains:

- Air Traffic Control - Training and Procedures;
- Airport Facilities;
- Aircraft Equipment; and,
- Aircraft Operations and Training.

All conclusions and recommendations were data-driven and supported by factual evidence of their relevance to the reduction of approach-and-landing incidents and accidents.

III Statistical Data

Approach-and-landing accidents (defined as accidents occurring during the initial approach, final approach and landing) represent approximately 55 % of total hull losses and 50 % of fatalities.

The flight segment from the outer marker to the completion of the landing roll represents only 4 % of the flight time but 45 % of hull losses.

These statistical data have not shown any down trend over the past 40 years.

Five types of events account for 75 % of approach-and-landing incidents and accidents:

- CFIT (including landing short of runway);
- Loss of control;
- Runway overrun;
- Runway excursion; and,
- Unstabilized approaches.

IV Implementation

The conclusions and recommendations of the ALAR Task Force needed to be translated into industry actions to ensure their effective implementation.

The Flight Safety Foundation committed to a significant awareness campaign that ensures availability of this information to everyone who participates in approach and landing operations, so that all can play a part in improving safety within their sphere of influence.

The cooperation and contribution of all players in the global aviation system are required to:

- Enhance *partnership*, *cooperation* and *communication* between:
  - operators (commercial, cargo, corporate);
  - national and international airline associations;
  - national and international pilot associations;
  - air traffic control services;
  - state operational authorities;
  - state navigation agencies;
  - services providers;
  - training organizations; and,
  - manufacturers.

- Achieve a *wide dissemination* of the ALAR education and training aid (ALAR Tool Kit), including:
  – CFIT and ALAR awareness videos;
  – Briefing Notes;
  – Presentations, for briefings to management level;
  – Safety Alert Bulletins;
  – Risk Awareness Tool; and,
  – Risk Reduction Guide.

- Facilitate an *easy and fast implementation* of all conclusions and recommendations.

V Operations and Training Overview

V.1 Standard Operating Procedures (SOPs) :

Conclusions:

- Establishing and adhering to adequate standard operating procedures (SOPs) improves approach and landing safety.
- The omission of an action or an inappropriate action rank:
  – As a causal factor, along with other factors, in 45 % of fatal approach-and-landing events; and,
  – A factor, to some degree, in 70 % of all approach-and-landing accidents.

Recommendations:

- State should mandate and operators should develop and implement SOPs for approach-and -landing operations;
- Operators should develop SOPs that allow their practical application in normal operating environment;

  The involvement of flight crews is essential in the development and evaluation of SOPs;

- Operators should implement routine and critical evaluation of SOPs to determine the need for change;
- Operators should develop SOPs regarding the use of automation during the approach and landing phases and provide training accordingly;

  Errors in using and managing the automatic flight system and/or the lack of awareness of the operating modes are causal factors in more than 20 % of approach-and-landing accidents;

- Operators should define a clear policy regarding the role of the pilot-in-command (commander) in complex and demanding situations;

  Training should address the practice of transferring flying duties during operationally complex situations.

V.2 Flightcrew Decision-Making :

Conclusions:

- Establishing and adhering to adequate decision-making processes improve approach and landing safety.
- Crew resource management issues, including decision-making under stress, are observed as circumstantial factors in more than 70 % of approach-and-landing accidents.

Recommendations:

- Operators should provide education and training that enhance flightcrew decision making and risk (error) management; and,
- Operators should develop an effective tactical decision-making model for use in time-critical situations.

V.3 Preparedness to Go-around and Commitment for Missed-Approach :

Conclusions:

- Failure to recognize the need for and to execute a missed approach when appropriate is a major cause of approach and landing accidents.
- More than 70 % of approach-and-landing accidents contained elements which should have been recognized by the crew as improper and which should have prompted a go-around.
- It is also observed than when an unstable approach warrants a go-around decision, less than 20 % of flightcrews actually initiate a go-around.

Recommendations:

- Operators should specify well-defined go-around gates for approach and landing operations. Go-around parameters should include:
  - Visibility minima required for the approach and landing operation;
  - Assessment at the final approach fix (FAF) or outer marker (OM) of crew and aircraft readiness for approach; and,
  - Minimum altitude at which the aircraft must be stabilized;

- Operators should develop and support *No-blame Go-around and Missed Approach Policies*;

  A true no-blame go-around policy should alleviate the reporting and justification requirements following a go-around or diversion; and,

- Training and company performance management systems should reinforce these policies.

V.4 Flying Stabilized Approaches :

Conclusions:

- Unstabilized and rushed approaches contribute to approach and landing accidents.
- Continuing an unstabilized approach is a causal factor in 40 % of all approach and landing accidents.
- Approximately 70 % of rushed and unstable approaches involve an incorrect management of the descent-and-approach profile and/or energy level (i.e., being slow and/or low, being fast and/or high).

Recommendations:

- Operators should define the parameters of a stabilized approach in their flight operations manuals (policy manual) and/or in their aircraft operating manual (AOM), including at least the following elements:
  - Intended flight path;
  - Speed;
  - Power setting;
  - Attitude;
  - Sink rate;
  - Configuration; and,
  - Crew readiness.

- All flights should be stabilized by 1000-ft (300m) height above airfield elevation in instrument meteorological conditions (IMC) and by 500-ft (150m) above airfield elevation in visual meteorological conditions (VMC).

- The approach should be considered stabilized only if:
  - The aircraft is on the correct flight path;
  - Only small changes in heading and pitch are required to maintain that path;
  - The airspeed is:
    - ❖ not more than V_{APP} + 10 kt IAS; and,
    - ❖ not less than V_{APP} – 5 kt;

    Note :

    The above recommendation has been adapted to reflect the Airbus V_{APP} concept.
  - The aircraft is in the proper landing configuration;
  - The sink rate is not greater than 1 000 ft/mn;
    - ❖ If an approach requires a sink rate greater than 1 000 ft/mn, a special briefing is required;
  - The power setting is appropriate for the configuration and not below the minimum power for approach, as defined in the aircraft operating manual, as applicable; and,
  - All briefings and checklists have been performed;

- In addition, LOC-only and ILS approaches are considered stabilized if they also fulfill the following:
  - LOC-only approaches must be flown within one dot of the localizer;
  - CAT I ILS approaches must be flown within one dot of the glide slope (GS) and localizer (LOC); and,
  - CAT II or CAT III ILS approaches must be flown within the glide slope and localizer excessive deviation warnings;

    Note :

    The above recommendation has been adapted to reflect the Airbus LOC and GS excessive deviation warnings.

- During visual approaches, wings must be level on final when the aircraft reaches 500 ft above airfield elevation;
- During circling approaches, wings must be level on final when the aircraft reaches 300 ft airfield elevation;
- Unique approaches may require a special briefing;
- Company policy (policy manual or SOPs) should state that a go-around is required if the aircraft becomes unstabilized during the approach;

- The implementation of certified constant-angle procedures for non-precision approaches should be expedited globally;
- Flight crews should be trained on the proper use of constant-angle, stabilized approach procedures;
- Flight crews should be educated on the approach design-criteria and minimum obstacle-clearance requirements (i.e., for each segment of the approach); and,
- Flightcrews should "take time to make time" whenever cockpit situation becomes confusing or ambiguous.

V.5 Pilot / Controller Communications :

Conclusions:

- Improving communication and mutual understanding between air traffic control services and flight crews of each other's operational environment will improve approach and landing safety.
- ATC instructions or information are causal factors in more than 30 % of approach-and-landing accidents, this includes incorrect or inadequate :
  - ATC instructions;
  - Weather or traffic information; and/or,
  - Advice/service in case of emergency,
- Approximately 70 % of altitude deviations are the result of a breakdown in the controller / pilot communication loop.

Recommendations:

ATC services and operators should:

- Introduce joint training that involves both ATC personnel and flight crews to:
  - Promote mutual understanding of issues such as procedures, instructions, operational requirements and limitations between flight deck and the ATC environment;
  - Improve controllers' knowledge of the capabilities advanced technology flight decks; and,
  - Foster improved communications and task management by pilots and controllers during emergency situations; and,
- Ensure that controllers are aware of the importance of unambiguous information exchange, particularly during in-flight emergencies;
- Implement procedures that require immediate clarification or verification of transmissions from flight crews that indicate a possible emergency situation;

- Implement procedures for ATC handling of aircraft in emergency situations to minimize flight crew distraction;
- In cooperation with airport authorities and rescue services, implement unambiguous emergency procedures and common phraseology to eliminate confusion; and,
- Develop, jointly with airport authorities and local rescue services, emergency training programs that are conducted on a regular basis.

Flight crews should:

- Verify understanding of each ATC communication and request clarification when necessary; and,
- Accurately report the status of abnormal and emergency situations and the need for emergency assistance using standard phraseology.

V.6 Approach Hazards - Low Visibility, Visual Illusions and Contaminated Runway Operations :

Conclusions:

- The risk of approach and landing accident is higher in operations conducted in low light and/or visibility, on wet or otherwise contaminated runways, and with the presence of optical or physiological illusions.
- More than 70 % of CFIT and runway excursion/overrun events occur:
  - In low visibility;
  - In hilly or mountainous terrain;
  - On contaminated runway; and/or,
  - Under adverse wind conditions.
- The lack of acquisition or the loss of visual references is the most common primary causal factor in approach-and-landing accidents.

Recommendations:

- Flight crews should be trained in operations involving adverse conditions (i.e., crosswind, runway contamination) before they are assigned line duties;
- Flight crews should make operational use of a risk-assessment checklist to identify approach and landing hazards;

  Appropriate procedures should be implemented to lessen these risks; and,
- Operators should develop and implement a policy for the appropriate use of automation, navigation and approach aids for the approach being flown.

V.7 Use of Radio Altimeter for Terrain Awareness :

Conclusions:

- Using the radio altimeter (RA) as an effective tool helps prevent approach and landing accidents.

Recommendations:

- Education is needed to improve crew awareness of radio altimeter operation and benefits;
- Operators should state that the radio altimeter is to be used during approach operations and specify procedures for its use; and,
- Operators should fit radio altimeters and activate “Smart Callouts” at 2,500 feet, 1,000 feet, 500 feet, at 200 feet or the altitude set in the “DH” (decision height) window (as well as at 50 ft, 40 ft, 30ft, 20 ft and 10 ft, as required) for enhanced terrain awareness.

V.8 Flight Operations Quality Assurance (FOQA) :

Conclusions:

Collection and analysis of in-flight parameters, (FOQA) programs identify performance trends that can be used to improve approach and landing safety.

Recommendations:

- FOQA should be implemented worldwide in tandem with information sharing partnerships such as the Global Analysis and Information Network (GAIN), the British Airways Information System (BASIS) and the Aviation Safety Action Partnership (ASAP);

  Note :

  The Airbus Flight Operations Monitoring (FOM) package meets the FOQA requirements for flight data analysis and monitoring (LOMS / AirFASE software), line observation (LOAS software) and crew reporting (AIRS software).

- Examples of FOQA benefits (safety improvements and cost reduction) should be publicized widely; and,
- A process should be developed to bring FOQA and information sharing partnerships to regional and corporate aviation.

V.9 Aviation Information Sharing :

Conclusions:

- Global sharing of aviation information decreases the risk of approach-and-landing accidents.

Recommendations:

- De-identification of aviation information data sources should be a cardinal rule in FOQA and information sharing processes; and,
- Public awareness of the importance of information sharing must be heightened through a coordinated effort.

V.10 Optimum Use of Current Technology/Equipment :

Although the Task Force issued conclusions and recommendations for future technological developments, operators should consider the immediate benefit of existing technology and equipment such as:

- Terrain Awareness and Warning System (TAWS), for enhanced terrain awareness and early warning of reduced terrain separation;
- Quick Access Recorder (QAR) and use Flight Operations Quality Assurance (FOQA) to detect and correct unsafe trends;
- Radio altimeter with smart callouts for enhanced terrain awareness;
- Precision approach guidance whenever available and use of VASI / PAPI in support of visual segment;
- GPS-based lateral navigation and barometric vertical navigation (pending the availability of GPS Landing System [GLS] approaches through the use of GNSS or GPS Local Area Augmentation System (LAAS);
- Mechanical or electronic checklists to improve checklist compliance (particularly in case of distraction or interruption);
- Approach and airport familiarization programs based on:
  - High-resolution paper material;
  - Video display; and/or
  - Simulator visual; and,
- Communication / Navigation / Surveillance (CNS) equipment such as Controller/Pilot Data Link Communication (CPDLC).

VI Reference Document

The following Special FSF Report provides a consolidated source of statistical data, definitions and facts about approach-and-landing accidents, including those involving CFIT:

Flight Safety Foundation

Flight Safety Digest

Killers in Aviation:

FSF Task Force Presents Facts

About Approach-and-landing and

Controlled-flight-into-terrain Accidents

Volume 17/No 11-12 – Volume 18/No 1-2

Nov.-Dec.98/Jan.-Feb.99

This Flight Operations Briefing Note (FOBN) has been developed by Airbus in the frame of the Approach-and-Landing Accident Reduction (ALAR) international task force led by the Flight Safety Foundation.

This FOBN is part of a set of Flight Operations Briefing Notes that provide an overview of the applicable standards, flying techniques and best practices, operational and human factors, suggested company prevention strategies and personal lines-of-defense related to major threats and hazards to flight operations safety.

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FLIGHT SAFETY FOUNDATION

ALAR

APPROACH-AND-LANDING ACCIDENT REDUCTION

TOOL KIT

FSF ALAR BRIEFING NOTE 7.1

Stabilized Approach

Unstabilized approaches are frequent factors in approach-and-landing accidents (ALAs), including those involving controlled flight into terrain (CFIT).

Unstabilized approaches are often the result of a flight crew who conducted the approach without sufficient time to:

- Plan;
- Prepare; and,
- Conduct a stabilized approach.

Statistical Data

The Flight Safety Foundation Approach-and-landing Accident Reduction (ALAR) Task Force found that unstabilized approaches (i.e., approaches conducted either low/slow or high/fast) were a causal factor[1] in 66 percent of 76 approach-and-landing accidents and serious incidents worldwide in 1984 through 1997.[2]

The task force said that although some low-energy approaches (i.e., low/slow) resulted in loss of aircraft control, most involved CFIT because of inadequate vertical-position awareness.

The task force said that the high-energy approaches (i.e., high/fast) resulted in loss of aircraft control, runway overruns and runway excursions, and contributed to inadequate situational awareness in some CFIT accidents.

The task force also found that flight-handling difficulties (i.e., the crew's inability to control the aircraft to the desired flight parameters [e.g., airspeed, altitude, rate of descent]) were a causal factor in 45 percent of the 76 approach-and-landing accidents and serious incidents.

The task force said that flight-handling difficulties occurred in situations that included rushing approaches, attempts to comply with demanding air traffic control (ATC) clearances, adverse wind conditions and improper use of automation.

Definition

An approach is stabilized only if all the criteria in company standard operating procedures (SOPs) are met before or when reaching the applicable minimum stabilization height.

The stabilized approach criteria recommended by the FSF ALAR Task Force are shown on the next page.

Note: Flying a stabilized approach that meets the recommended criteria discussed below does not preclude flying a delayed-flaps approach (also referred to as a decelerated approach) to comply with ATC instructions.

The following minimum stabilization heights are recommended to achieve a stabilized approach:

- 1,000 feet above airport elevation in instrument meteorological conditions (IMC); or,
- 500 feet above airport elevation in visual meteorological conditions (VMC).

At the minimum stabilization height and below, a call should be made by the pilot not flying/pilot monitoring (PNF/PM) if any flight parameter exceeds the established criteria.

Any time an approach is not stabilized at the minimum stabilization height or becomes unstabilized below the minimum stabilization height, a go-around should be conducted.

Benefits of a Stabilized Approach

Conducting a stabilized approach increases the flight crew's overall situational awareness, including:

- Horizontal awareness, by closely monitoring the horizontal flight path;
- Vertical awareness, by monitoring the vertical flight path and the rate of descent;
- Airspeed awareness, by monitoring airspeed trends; and,

Recommended Elements of a Stabilized Approach

All flights must be stabilized by 1,000 ft above airport elevation in instrument meteorological conditions (IMC) and by 500 ft above airport elevation in visual meteorological conditions (VMC). An approach is stabilized when all of the following criteria are met:

1. The aircraft is on the correct flight path;
2. Only small changes in heading/pitch are required to maintain the correct flight path;
3. The aircraft speed is not more than V_{REF} + 20 kt indicated airspeed and not less than V_{REF};
4. The aircraft is in the correct landing configuration;
5. Sink rate is no greater than 1,000 fpm; if an approach requires a sink rate greater than 1,000 fpm, a special briefing should be conducted;
6. Power setting is appropriate for the aircraft configuration and is not below the minimum power for approach as defined by the aircraft operating manual;
7. All briefings and checklists have been conducted;
8. Specific types of approaches are stabilized if they also fulfill the following: instrument landing system (ILS) approaches must be flown within one dot of the glideslope and localizer; a Category II or Category III ILS approach must be flown within the expanded localizer band; during a circling approach, wings should be level on final when the aircraft reaches 300 ft above airport elevation; and,
9. Unique approach procedures or abnormal conditions requiring a deviation from the above elements of a stabilized approach require a special briefing.

An approach that becomes unstabilized below 1,000 ft above airport elevation in IMC or below 500 ft above airport elevation in VMC requires an immediate go-around.

Source: FSF ALAR Task Force

- Energy-condition awareness, by maintaining the engine thrust at the level required to fly a three-degree approach path at the target final approach speed (or at the minimum groundspeed, as applicable). This also enhances go-around capability.

In addition, a stabilized approach provides:

- More time and attention for monitoring ATC communications, weather conditions and systems operation;
- More time for monitoring and backup by the PNF/PM;
- Defined flight-parameter-deviation limits and minimum stabilization heights to support the decision to land or to go around; and,
- Landing performance consistent with published performance.

Factors in Unstabilized Approaches

Unstabilized approaches are attributed to:

- Fatigue;
- Pressure of flight schedule (making up for delays);
- Any crew-induced or ATC-induced circumstances resulting in insufficient time to plan, prepare and conduct a safe approach. This includes accepting requests from ATC to fly higher/faster or to fly shorter routings than desired;
- ATC instructions that result in flying too high/too fast during the initial approach;
- Excessive altitude or excessive airspeed (e.g., inadequate energy management) early in the approach;
- Late runway change (lack of ATC awareness of the time required by the flight crew to reconfigure the aircraft for a new approach);
- Excessive head-down work (e.g., flight management system [FMS] reprogramming);
- Short outbound leg or short downwind leg (e.g., because of traffic in the area);
- Late takeover from automation (e.g., because the autopilot [AP] fails to capture the glideslope);
- Premature descent or late descent caused by failure to positively identify the final approach fix (FAF);
- Inadequate awareness of wind conditions, including:
  - Tail wind component;
  - Low-altitude wind shear;
  - Local wind gradient and turbulence (because of terrain or buildings); or,
  - Recent weather along the final approach path (e.g., wind shift or downdrafts caused by a descending cold air mass following a rain shower);
- Incorrect anticipation of aircraft deceleration characteristics in level flight or on a three-degree glide path;
- Failure to recognize deviations or failure to adhere to the excessive-parameter-deviation limits;
- Belief that the aircraft will be stabilized at the minimum stabilization height or shortly thereafter;
- Excessive confidence by the PNF/PM that the pilot flying (PF) will achieve a timely stabilization;
- PF-PNF/PM too reliant on each other to call excessive deviations or to call for a go-around; and,
- Visual illusions.

Deviations in Unstabilized Approaches

One or more of the following deviations often are involved in unstabilized approaches:

- Entire approach flown at idle thrust down to touchdown, because of excessive airspeed and/or excessive altitude from early in the approach;
- Steep approach (above desired flight path with excessive vertical speed). Steep approaches are conducted typically twice as often as shallow approaches;
- Shallow approach (below desired glide path);
- Low-airspeed maneuvering (energy deficit);
- Excessive bank angle when capturing the final approach course;
- Activation of the ground-proximity warning system (GPWS) or the terrain awareness and warning system (TAWS)[3]:
  - Mode 1: "sink rate";
  - Mode 2A: "terrain" (not full flaps); or,
  - Mode 2B: "terrain" (full flaps);
- Late extension of flaps, or flaps-load-relief-system activation resulting in the late extension of flaps;
- Excessive flight-parameter deviation when crossing the minimum stabilization height:
  - Excessive airspeed;
  - Not aligned with runway;
  - Excessive bank angle;
  - Excessive vertical speed; or,
  - Flight path above glideslope;
- Excessive bank angle, excessive sink rate or excessive maneuvering while conducting a side-step maneuver;
- Speed brakes remain extended on short-final approach;
- Excessive flight-parameter deviation down to runway threshold;
- High at runway threshold crossing (i.e., more than 50 feet above threshold); and,
- Extended flare and extended touchdown.

Company Accident-Prevention Strategies and Personal Lines of Defense

Preventing unstabilized approaches can be achieved by developing recommendations for the early detection and correction of factors that contribute to an unstabilized approach.

The following strategy is recommended:

- Anticipate;
- Detect;
- Correct; and,
- Decide.

Anticipate

Some factors likely to result in an unstabilized approach can be anticipated. For example, pilots and controllers should avoid situations that result in rushing approaches.

The approach briefing provides opportunities to identify and discuss factors such as nonstandard altitude, airspeed restrictions and energy management. The flight crew should agree on the management of the descent, deceleration and stabilization. This agreement will constitute a common objective for the PF and PNF/PM.

Detect

The purpose of defined excessive-parameter-deviation limits and minimum stabilization heights is to provide the PF and PNF/PM with a common reference for effective monitoring (early detection of deviations) and backup (timely and precise calls for effective corrections).

To ensure monitoring and backup, the following should be avoided:

- Late briefings;
- Unnecessary radio calls (e.g., company calls);
- Unnecessary actions (e.g., use of airborne communications addressing and reporting system [ACARS]); and,
- Nonpertinent conversations on the flight deck (i.e., breaking the "sterile cockpit rule"[4]).

Reducing workload and flight deck interruptions/distractions also allows the flight crew to:

- Better cope with fatigue;
- Comply with an unexpected ATC request (e.g., runway change);
- Adapt to changing weather conditions; and,
- Manage a system malfunction (e.g., flaps jamming or landing gear failing to extend).

Correct

Positive corrective actions should be taken before deviations develop into a challenging situation or a hazardous situation in which the only safe action is a go-around.

Corrective actions may include:

- The timely use of speed brakes or landing gear to correct excessive height or excessive airspeed; and,
- Extending the outbound leg or downwind leg.

Decide

If the approach is not stabilized before reaching the minimum stabilization height, or if any flight parameter exceeds deviation limits (other than transiently) when below the minimum stabilization height, a go-around must be conducted immediately.

The following behaviors often are involved when unstabilized approaches are continued:

- Excessive confidence in a quick recovery (postponing the go-around decision when flight parameters are converging toward excessive-deviation limits);
- Excessive confidence because of a long-and-dry runway and a low gross weight, although airspeed or vertical speed may be excessive;
- Inadequate preparation or lack of commitment to conduct a go-around. A change of mindset should take place from "we will land unless ..." to "let's be prepared for a go-around, and we will land if the approach is stabilized and if we have sufficient visual references to make a safe approach and landing"; and,
- Absence of decision making (failure to remember the applicable excessive-deviation limits) because of fatigue or workload.

Achieving Flight Parameters

The flight crew must "stay ahead of the aircraft" throughout the flight. This includes achieving desired flight parameters (e.g., aircraft configuration, aircraft position, energy condition, track, vertical speed, altitude, airspeed and attitude) during the descent, approach and landing. Any indication that a desired flight parameter will not be achieved should prompt immediate corrective action or the decision to go around.

The minimum stabilization height constitutes an *approach gate*[5] on the final approach; a go-around must be initiated if:

- The required configuration and airspeed are not established, or the flight path is not stabilized when reaching the minimum stabilization height; or,
- The aircraft becomes unstabilized below the minimum stabilization height.

Transition to Visual Flying

When transitioning from instrument flight to visual flight, the pilot's perception of the runway and outside environment should be kept constant by maintaining:

- Drift correction, to continue tracking the runway centerline (i.e., resisting the tendency to align the aircraft with the runway centerline);
- The aiming point, to remain on the correct glide path until flare height (resisting the tendency to advance the aiming point and, thus, descend below the correct glide path); and,
- The final approach speed to maintain the energy condition.

Summary

Three essential parameters must be stabilized for a safe approach:

- Aircraft track;
- Flight path angle; and,
- Airspeed.

Depending on the type of approach and aircraft equipment, the most appropriate level of automation, as well as available visual references, should be used to establish and to monitor the stabilization of the aircraft.

The following FSF ALAR Briefing Notes provide information to supplement this discussion:

- 4.1 — Descent-and-Approach Profile Management;
- 4.2 — Energy Management;
- 6.1 — Being Prepared to Go Around;
- 7.2 —Constant-Angle Nonprecision Approach;
- 8.2 — The Final Approach Speed; and,
- 8.3 — Landing Distances.

Notes

1. The Flight Safety Foundation Approach-and-landing Accident Reduction (ALAR) Task Force defines *causal factor* as "an event or item judged to be directly instrumental in the causal chain of events leading to the accident [or incident]." Each accident and incident in the study sample involved several causal factors.
2. Flight Safety Foundation. "Killers in Aviation: FSF Task Force Presents Facts About Approach-and-landing and Controlled-flight-into-terrain Accidents." *Flight Safety Digest* Volume 17 (November–December 1998) and Volume 18 (January–February 1999): 1–121. The facts presented by the FSF ALAR Task Force were based on analyses of 287 fatal approach-and-landing accidents (ALAs) that occurred in 1980 through 1996 involving turbine aircraft weighing more than 12,500 pounds/5,700 kilograms, detailed studies of 76 ALAs and serious incidents in 1984 through 1997 and audits of about 3,300 flights.
3. Terrain awareness and warning system (TAWS) is the term used by the European Aviation Safety Agency and the U.S. Federal Aviation Administration to describe equipment meeting International Civil Aviation Organization standards and recommendations for ground-proximity warning system (GPWS) equipment that provides predictive terrain-hazard warnings. "Enhanced GPWS" and "ground collision avoidance system" are other terms used to describe TAWS equipment.
4. The *sterile cockpit* rule refers to U.S. Federal Aviation Regulations Part 121.542, which states: "No flight crewmember may engage in, nor may any pilot-in-command permit, any activity during a critical phase of flight which could distract any flight crewmember from the performance of his or her duties or which could interfere in any way with the proper conduct of those duties. Activities such as eating meals, engaging in nonessential conversations within the cockpit and nonessential communications between the cabin and cockpit crews, and reading publications not related to the proper conduct of the flight are not required for the safe operation of the aircraft.

For the purposes of this section, critical phases of flight include all ground operations involving taxi, takeoff and landing, and all other flight operations below 10,000 feet, except cruise flight." [The FSF ALAR Task Force says that "10,000 feet" should be height above ground level during flight operations over high terrain.]

5. The FSF ALAR Task Force defines *approach gate* as "a point in space (1,000 feet above airport elevation in instrument meteorological conditions or 500 feet above airport elevation in visual meteorological conditions) at which a go-around is required if the aircraft does not meet defined stabilized approach criteria."

Related Reading From FSF Publications

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FSF Editorial Staff. "Poorly Flown Approach in Fog Results in Collision With Terrain Short of Runway." *Accident Prevention* Volume 52 (August 1995).

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Lawton, Russell. "Steep Turn by Captain During Approach Results in Stall and Crash of DC-8 Freighter." *Accident Prevention* Volume 51 (October 1994).

Lawton, Russell. "Breakdown in Coordination by Commuter Crew During Unstabilized Approach Results in Controlled-flight-into-terrain Accident." *Accident Prevention* Volume 51 (September 1994).

FSF Editorial Staff. "Unstabilized Approach, Icing Conditions Lead to Commuter Tragedy." *Accident Prevention* Volume 49 (December 1992).

Notice

The Flight Safety Foundation (FSF) Approach-and-Landing Accident Reduction (ALAR) Task Force produced this briefing note to help prevent approach-and-landing accidents, including those involving controlled flight into terrain. The briefing note is based on the task force's data-driven conclusions and recommendations, as well as data from the U.S. Commercial Aviation Safety Team's Joint Safety Analysis Team and the European Joint Aviation Authorities Safety Strategy Initiative.

This briefing note is one of 33 briefing notes that comprise a fundamental part of the FSF *ALAR Tool Kit*, which includes a variety of other safety products that also have been developed to help prevent approach-and-landing accidents.

The briefing notes have been prepared primarily for operators and pilots of turbine-powered airplanes with underwing-mounted engines, but they can be adapted for those who operate airplanes with fuselage-mounted turbine engines, turboprop power plants or piston engines. The briefing notes also address operations with the following: electronic flight instrument systems; integrated autopilots, flight directors and autothrottle systems; flight management systems; automatic ground spoilers; autobrakes; thrust reversers; manufacturers'/operators' standard operating procedures; and, two-person flight crews.

This information is not intended to supersede operators' or manufacturers' policies, practices or requirements, and is not intended to supersede government regulations.

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